Stakeholder benefits of intelligent stand-alone lighting solutions

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ABSTRACT OF THE
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Stand-alone lighting solution is a term often used with systems that are designed to operate independently and in a simple way. The aim of this thesis is to analyse the benefits that intelligent stand-alone lighting solutions can offer to various stakeholders.

In addition to discussing the technology and definition of stand-alone solutions, three concepts of a Finnish company Helvar are introduced and compared to other competing products on the market. Energy consumption of one concept in five case installations in offices and a lecture hall is analysed and clear savings are found. The measurability of ease of use is discussed and easyness as a benefit is evaluated with the three concepts.

To gather input and feedback from professionals and stakeholders themselves, face-to-face and email interviews were made and results are analysed and presented. The overall response to the stand-alone solutions was good, and clear benefits and challenges were acknowledged and improvement ideas suggested. When conducting a survey among the interviewees, reliability, ease of use and energy efficiency were raised to the lighting control factors that are considered the most important.

Keywords: Stand-alone, lighting, control, stakeholder, LED, DALI

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Itsenäinen valaistusratkaisu on termi, jota käytetään usein puhuttaessa systeemeistä, jotka on suunniteltu toimimaan riippumattomasti ja yksinkertaisesti. Tämän diplomityön tarkoitus on analysoida hyötyjä, joita itsenäiset älykkäät valaistusratkaisut pystyvät tarjoamaan eri sidosryhmille.
Itsenäisten valaistusratkaisujen määritelmän ja niiden taustalla olevan teknologian käsittelemisen lisäksi työssä esitellään suomalaisen valaistusalan yrityksen Helvarin kolme eri valaistuskonseptia. Niitä myös vertaillaan markkinoilla oleviin muihin kilpaileviin tuotteisiin. Yhden konseptin energiankulutusta analysoidaan viidessä eri kohteessa, joissa valaisimia on asennettu luokkahuoneeseen sekä toimistoihin, ja selkeitä säästöjä pystytään havaitsemaan. Helppokäyttöisyyden mittareita pohditaan, ja helppoutta yhtenä hyötynä tarkastellaan sekä arvioidaan kolmen konseptin osalta eri sidosryhmien näkökulmista.
Jotta palautetta ja mielipiteitä kuultaisiin myös ammattilaisilta sekä eri sidosryhmiltä itseltään, haastatteluja tehtiin sekä kasvokkain että sähköpostilla, ja tulokset analysoidaan ja esitetään tässä työssä. Yleinen vastaanotto itsenäisiä valaistusratkaisuja kohtaan oli hyvä, ja selkeitä hyötyjä sekä haasteita tunnistettiin. Myös parannusehdotuksia esitettiin. Kun haastateltaville tehtiin kysely, luotettavuus, helppokäyttöisyys ja energiatehokkuus nousivat lopulta valaistuksen ohjauksen ominaisuuksiksi, joita pidetään kaikkein tärkeimpinä.

Avainsanat: Itsenäinen, valaistus, ohjaus, sidosryhmä

Preface

I want to thank both my supervisor professor Liisa Halonen for her advices and genuine interest in my thesis, and my instructor Henri Juslén for providing this master's thesis topic and also for his great guidance and encouragement during this process.

Collegues at Helvar have helped me in many problems and guided me with the thesis. I want to thank Måns Paul for his support and knowledge he shared with me, Pekka Vuorio and Aki Lankinen for helping with software-related questions, Jukka Ahola for peer support, Markku Muurinen for providing me building floor plans and all the other people at Helvar for creating the great working atmosphere. Special thanks also to Oliver Weiss from Helvar Germany, Antoine Cussac from Helvar France, Andrew Glossop from Helvar UK, Jorma Martikainen from Ensto Lighting and everybody who helped me in this project.

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Espoo, October 27, 2015

Toni P. Malinen

Contents

Abbreviations

A/V	Audio/video
BMS	Building management system
CCT	Correlated colour temperature
CCO	Contact closure output
CL	Constant light
CLO	Constant lumen output
CRI	Colour rendering index
DALI	Digital Addressable Lighting Interface
DLA	(Digital Lumens) Digital Light Agent
DSI	Digital Serial Interface
HID	High-intensity discharge
HVAC	Heating, ventilation and air conditioning
ICT	Information and communications technology
ipRGC	Intrinsically photosensitive retinal ganglion cells
LED	Light emitting diode
NEMA	National Electrical Manufacturers Association
PIR	Passive infrared
PLC	Power line communications
SELV	Separated or safety extra-low voltage
SLC	(Osram) Street Light Control
VDC	Volts of direct current
VPO	Virtual power output

1 Introduction

Lighting is a major part of our everyday life and surroundings, affecting the health, mood and motivation of the people. The use of artificial light sources is a burden in economical and environmental sense too, as approximately 19% of the electricity used in the world is consumed by lighting [1]. Lighting industry is going through a major change in the sense of new possibilities, trends and focus points emerging. Market share of the light emitting diode (LED) lighting is growing all the time as the technology improves. LEDs are gaining competitive edge in increasingly more applications in indoor and outdoor lighting compared to the older incandescent, fluorescent and high-intensity discharge (HID) lamps.

Market penetration of the sales of LED technology in total lighting sales is forecasted to reach and pass 40% in 2015. [2] LED troffers and high/low-bay luminaires are already improved past the other technologies in terms of luminous efficacy and lifetime. [3] When striving for even greater energy efficiency, the full potential of the LEDs lies in the smart and efficient control. It has been researched that combined control methods of occupancy control, daylight sensing and personal and location-specific tuning can achieve an average of 38% energy savings in commercial buildings compared to traditional switched lighting [4]. Combined controls with LED luminaires [5] and fluorescent tube luminaires (see chapter 5.1) have achieved notable energy savings in office environment case studies.

In the beginning the lighting controls included mainly dimmers for incandescent lamps, and the analog and digital control signal protocols came later. Before digital protocols, 0-10V and 1-10 V analog control signals were widely used to indicate the desired dimming level of the connected luminaires. The Digital Serial Interface (DSI) protocol, owned by Tridonic, was released in 1991, and today it is mostly replaced by the open Digital Addressable Lighting Interface (DALI) protocol. [6]. To take the operating environment into account different kinds of sensors are used in lighting control systems. Common occupancy sensor technologies are passive infrared (PIR) and ultrasonic sensing. [7] Light sensors measure the available daylight or external light. Different sensors, microprocessors and wireless communication components are integrated in many lighting control solutions on the market today, as can be seen in chapter 4.

According to the Demulog and Elderathome EU projects where young families and senior citizens were interviewed, people hope that the lighting control systems would enhance control over the environment as well as improve comfort, safety and energy efficiency [8]. In addition to these benefits, market potential can depend on qualities such as ease of use, complexity of installation and investment costs, as comes clear in chapter 6.

Intelligent stand-alone solutions are a model of lighting control system that offers value for the customers through simplicity and independence. Even the traditional manually switched on/off solution can be regarded as stand-alone, but it has little

intelligence in the operation. In this thesis the term "stand-alone" in the field of lighting is defined to mean products and concepts which have features aimed for improving e.g. energy efficiency, ease of installation or ease of use compared to traditional manually switched lighting, but still capable of operating on their own. In addition to the power supply and possibly some kind of switch, no external infrastructure should be required for the stand-alone product to operate. Eventually all the solutions are designed to form a luminaire-centered system to produce and control the light.

This master's thesis is done in cooperation with Aalto University and Helvar, a Finnish company specialised in lighting components and control systems. Focus of the thesis is in stand-alone lighting solutions in general and also specifically three concepts that the company released to the market in 2015. Active+ is a self-learning luminaire concept, equipped with sensors to measure its surroundings and adapt to those. [9] NightDim allows easy controlling and scene setting to outdoor luminaires through a simple process of switching the mains voltage on and off. [10] Select the Weather makes use of DALI Type 8 protocol and tunable white technology allowing the user to set the colour temperature high, low or then changing automatically in a dynamic mode. [11]

The aim of this master's thesis is to analyse the advantages and challenges of stand-alone lighting solutions in the perspectives of different stakeholders. In lighting projects the stakeholders refer to people such as electrical designers, electricians, building managers and end users, who are involved in various phases of the project. This thesis analyses the question of which benefits do the stand-alone lighting solutions offer compared to other systems, and also what kind of differences are there between various stand-alone solutions on the market. Some of the benefits are measurable, such as energy savings. The measurability of ease of use is also discussed. In order to get feedback from the stakeholders themselves, interviews are done and results summarised.

In the first part of the thesis the technology and the market of lighting controls are discussed and three common control protocols are examined. In the next two chapters the three Helvar stand-alone concepts are presented and compared to competing products on the market. In the fifth chapter energy savings of Active luminaires are analysed and the ease of use of the lighting control solutions evaluated. In the last chapters the results of the stakeholder interviews are presented, discussed and conclusions are made.

2 Lighting technology

In the history of lighting, much of the development and improvement has been achieved in the technological advancement of light sources, from the incandescent bulbs to the new energy efficient and agile LEDs. Lighting controls have been weighing in recently, leading to even greater improvements in efficient lighting when combined with LEDs.

Energy efficiency has been a very substantial and possibly the most important goal of the lighting control for a long time. Apart from the obvious importance of saving energy, users and developers have been starting to focus their attention also on the impact that lighting can have on the mood, motivation and well-being of people. Along with the digitalization, there are a wide range of solutions available in the lighting market today, from the simple switches to complex control and management systems, operating as networked or stand-alone solutions.

2.1 Intelligent lighting control

Although being common terms in lighting market today, intelligent lighting or intelligent control do not have a clear established definitions. They might be associated with solutions capable of sensing their environment, devices that are connected to each other in networks, systems that make autonomic decisions etc. The common factor is that the intelligence aims for improving the operation and offering added value for the stakeholders such as designers, installers and users.

Modern lighting systems usually include luminaires and control systems that utilise sensor data and information and communications technology (ICT) based software features to provide better energy efficiency, comfort, usability and performance. Various solutions and products in the market introduced in chapters 3 and 4 show that the control systems include components such as sensors, controllers, timers, dimmers and their software. As seen in Table 1, the market of the control gear is predicted to grow substantially more compared to the market of light sources and luminaires. [2] More specified growth forecast for control gear market is presented in Figure 1. Although stating lower total control gear market values than in Table 1, it can still be seen that offices are the single largest segment where lighting controls are used.

Table 1 – Market forecast in billions (EUR) and compound annual growth rate (CAGR) for global lighting market. (Modified from [2])

Year/ billions EUR	Lightsources	Control gear	Fixtures
2014	17.3	6.1	42.4
2020	24.0	10.5	56.4
CAGR (2014 - 2020)	1.0 %	7.4 %	1.9 %

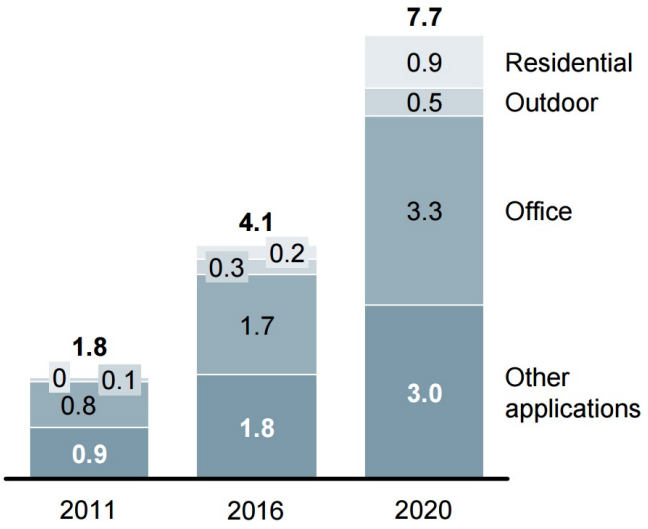

Figure 1 – Market forecast for lighting system control components in billions (EUR). Other application segments include architectural use of lighting for decorative and functional uses as well as the retail, industrial, hospitality and industrial market segments. [12]

As noted in chapter 1, LED light sources are increasing their market share constantly more while offering benefits in e.g. luminous efficacy, lifetime and control possibilities. However, there are a significant amount of fluorescent luminaires still in operation. 2010 in the United States the estimated percentage of linear fluorescent luminaires in use in the commercial sector was 80% while percentage of LED luminaires was only 1,8%. Linear fluorescent lighting used approximately 72% of all the electricity consumed in the lighting in the commercial sector. [13] According to market research, the share of fluorescent lighting in the total lighting market in the office applications globally was 69 % in 2012, while market share of LEDs was significantly lower, 11 % [12]. Most of the energy consumption case studies with Active solution in chapter 5.1 are measured also with fluorescent luminaires.

One of the simplest examples of an intelligent system is an office lighting control system, where the luminaires are dimmed when there is daylight available or switched off when the office is not occupied. New wireless technology enables more flexible installation and remote controlling, even from outside the building with tablets, mobile phones and computers. It is possible to connect lighting controls also to other systems that manage building services such as heating, ventilation and air conditioning.

When implementing lighting control systems in homes, offices, schools etc. there are other factors besides functionality to take into account too. Ease of use helps the users to be able to benefit from the functions. Installation is an essential step before taking the system into use, and complex rewiring, programming and commissioning can be a burdensome project. With all the new technologies being developed and used in the products, reliability is still an important characteristic that should not be compromised.

2.2 0-10V, 1-10V and DALI control protocols

When the different sensors, controllers and dimming ballasts and drivers communicate with each other, common control protocols are required. These enable the cooperation of products from different manufacturers, which is a benefit for the specifiers choosing products and systems.

The 0-10V protocol is defined in the standard NEMA ANSI C82.11 American National Standard for High Frequency Fluorescent Lamp Ballasts. In this protocol a two wire, polarity sensitive, parallel bus is connected to all controllable ballasts/drivers and to the controller. The basic wiring diagram is presented in Figure 2. The devices can typically withstand at least slightly higher voltages, but in nominal levels 10 volts of direct current (VDC) produces maximum light output and zero voltage switches the light off. 1 VDC produces minimum light output according to the standard, and a 1-10V protocol is also used in lighting controls market. The difference is that then a switch is needed to completely switch the light off. In case of reverse polarity, open circuits or controller failure, a minimum or maximum level of light is set. Ballasts/drivers are the source of the control current, and the controllers include variable resistors or electronic equivalents to adjust the voltage. [14]

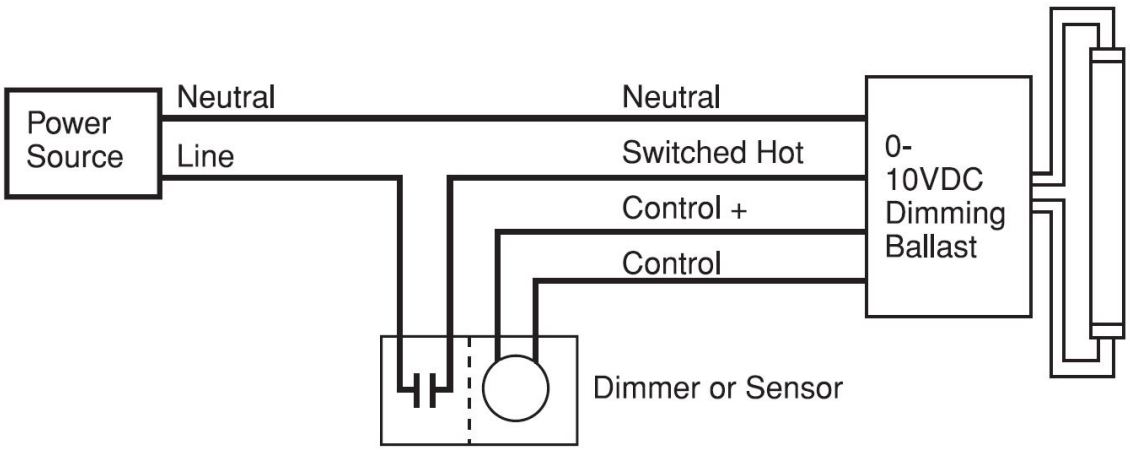

Figure 2 – An example of the wiring diagram for 0-10V dimming in case of fluorescent light source. The voltage between two polarity sensitive control cables from the dimmer or sensor control the dimming level of the ballast and light source. [14]

DALI stands for Digital Addressable Lighting Interface. DALI is a fully digital open protocol, and the companies joined into DALI group can use the protocol and DALI logo as long as the products pass the official tests. The protocol is set out in the technical standard IEC 62386. [6]

As an addressable protocol, every device in the subnet can be identified and controlled individually. Commands can be sent to specific addresses or then broadcasted to all. The data can be transmitted to both directions, meaning that in addition to controlling the luminaires, they can also send data about their status back to controllers. After the physical installation, all the devices in DALI network must be

commissioned however, before they operate correctly. To perform the initialisation a DALI trained installer and a programming interface or device is needed, but all the parameters from groups to lighting scenes and customised commands can be programmed as desired. [6, 14]

DALI has 254 dimming intensity levels with a non-linear dimming curve, and the digital data is sent over a pair of conductors at 1200 bits per second. The DALI polarity-free control cables may be installed in many topologies, such as star, daisy-chain, tree or combination, only loops are prohibited. An example of DALI system wiring diagram is presented in Figure 3. The total DALI cabling length must not exceed 300 meters, and one DALI subnet includes maximum of 64 addresses for devices like ballasts, drivers, dimmers or relays. Each subnet requires a power supply unit, and the total current must not exceed 250 mA. [6, 14] Cabling length and total current limits can although be increased with products like Helvar 405 DALI Repeater [15]. Multiple subnets can also be connected with routers and communication with other protocols is possible with gateways.

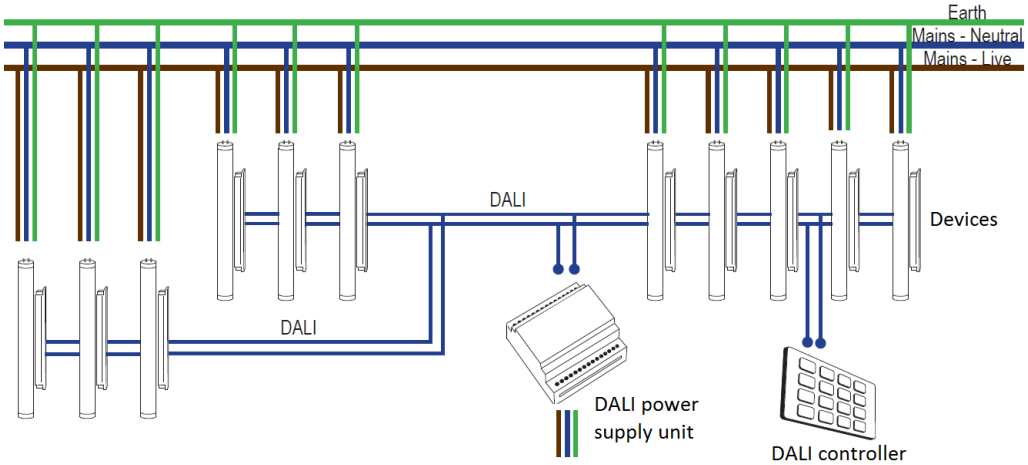

Figure 3 – An example of the wiring diagram of a DALI system. All the different components of the subnet i.e. the devices, controller and a power supply unit are connected together with DALI control cables (Modified from [6])

2.3 Stand-alone lighting solutions

The term stand-alone solution is often used with products and concepts which have value-adding features, but are intended to operate as an independent entity. It is although completely possible to integrate stand-alone solutions into being a part of a larger network too. As described in the chapter 1, in this thesis the definition of stand-alone solutions is specified to products that form a luminaire system that functions by itself without any additional devices other than switches or sensors. Offered benefits can be e.g. cost-efficiency for small projects, simplified usability and no requirements for programming or control wiring in installation, simplifying also the work of the electrical designer.

2.3.1 Advantages

There are many possible benefits of stand-alone solutions to different stakeholders. The easier the structure of the solutions is and the less different components there are, the easier is the task of designing the electrical schematics. Simple installation makes the project easier for the contractor, as there is less need for complex wirings and no trained programmer is needed on site. Especially in refurbishment projects solutions that offer convenient value-adding features with minimum need for specific renovation and installation can be more cost-efficient and preferable for the contractee compared to a large-scale networked automation system.

After the installation and during the actual use, many stand-alone solutions offer competitive advantages with ease of use. End users could be assumed to prefer the use of the actual lighting control system to be as easy and convenient as possible. Studies have shown, that according to the users the ease of use of lighting controls is one of the most essential factors in obtaining the most comfortable lighting conditions along with reduced energy consumption [16]. Controlling the system should be preferably as simple as how they currently control lighting in their homes [17]. This suggests that one notable benefit of stand-alone solutions may be indeed the ease of use.

Eventually one of the important factors when choosing the products to different projects is the required investment. Whether initial investment or running costs, money is essential and many contractees make decisions based on the costs as comes clear in the interviews in chapter 6. If the installation is demanding, the contractors have to charge high fees. In general, if the stand-alone solution is able to offer simple installation, energy saving features and affordable product price, the low total costs are a clear benefit.

Reliability and quality are often prerequisites for success in the market and major benefits for all stakeholders. Sometimes it is not possible for the manufacturers to sell forever-lasting products and naturally they want to sell new ones too, but generally reliability is highly appreciated among the different stakeholders (see chapter 6). Stand-alone products operate usually independently, and in case of malfuntioning they do not disturb the other ones. This is an advantage compared to networked system, where the error of one critical controller can impair the whole network. The information security is a factor that must be taken into consideration with the wired or wireless networks as well, and the distributed control reduces the risk of hackers taking control of the whole system.

2.3.2 Challenges

Challenging situations for stand-alone solutions are the installations where there are a notable amount of stand-alone products operating together. It must be then taken into consideration if the products can be controlled together in a common way, or are they totally independent systems. The management of large amount of stand-alone products can be a problem, if they do not operate optimally or adjustments must be

made. When renovating large projects, instead of hundreds of stand-alone products, centralised control and intelligence could be more optimal solution there.

Updating or upgrading stand-alone products must always be done individually, which does not favour large-scale installations either. With full integrated automation system the software in the central controller can be updated easier and adding new components or replacing old ones is more convenient. The feature scalability in the future is thus easier with networked lighting control system, although the reliability can suffer as earlier mentioned. When simulating different control strategies and their effects to energy consumption, Shen et al.[18] found that the integrated systems were likely to achieve greater energy saving potential and visual comfort in optimal operation than independent solutions, especially when connected to heating, ventilation, air conditioning and window blinds.

2.4 Summary

Along with the market penetration of LED technology in light sources, the energy efficiency is improving also with the implementation and development of lighting control systems. Besides the energy savings, the effects on well-being of people are taken into consideration when designing new lighting systems.

Intelligent lighting control today is implemented with the help of microprocessors, software, sensors and actuators. The market of control gear is forecasted to grow in the near future, and the increasing competition forces the manufacturers to pay more attention to characteristics such as ease of use and complexity of installation in control systems.

When different components of the control systems communicate with each other, control protocols serve as a common language. 0-10V and 1-10V standards are widely used analog protocols, which rely on signalling the dimming value via a certain control voltage level, requiring all the controlled devices to be cabled directly to the controller. The modern digital addressable lighting interface DALI uses digital commands that enable sophisticated and centralised programming of the system and less restricted cabling topology.

Stand-alone solutions in lighting are operating in a principle contrary to the centralised and networked systems, as even single luminaires can have the controlling intelligence built inside with no need for external infrastructure besides mains cable and possible switch or a sensor.

Advantages of stand-alone solutions can include benefits such as simple installation, ease of use, lower initial investments, quality, information security and reliability. The control of large amount of stand-alone products may prove challenging however, as well as upgrading them later.

3 Stand-alone lighting concepts in focus

This chapter introduces the three Helvar stand-alone concepts that are the primary focus in the thesis. There is plenty of technical documentation as well as marketing material about the solutions on the Helvar website, which is the primary source of all the informations presented in this chapter [9][10][11]. Internal material has also been used to gather details about the concepts.

3.1 Active+

Helvar Active+ is a self-learning luminaire concept, which offers basically automated use, simple installation and many energy saving features. The original Active has been on the market for some time and the new version, Active+, was released in September 2015. [9]

Active+ is targeted for all the customers who already use simple on/off switching luminaires or just appreciate the simplicity in the lighting controls. Helvar states that added value is gained through the intelligent learning and efficient operation.

As it is stated in the technical documentation, the concept consists of the Active+ LED driver with preprogrammed software and a multi-funtional sensor unit to be installed inside a luminaire. The driver and the sensor can be seen in Figure 4. The sensor unit includes a photosensor for measuring ambient light and a PIR sensor for detecting occupancy. PIR sensors in general operate by sensing the difference in heat emitted by humans in motion from that of the background space. The sensors detect motion within a certain field of view though, and that is defined by the lens on the sensor. [7]

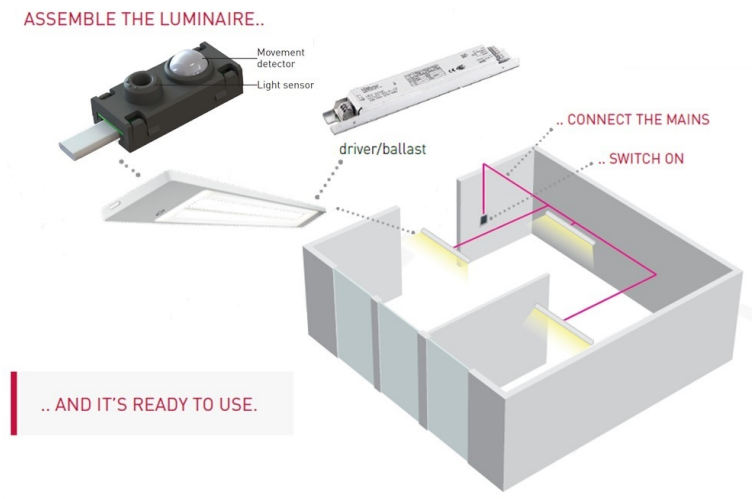

Figure 4 – When Active+ driver and the multi-funtional sensor are installed inside the luminaire, after connecting and switching on the mains voltage no further installation effort is needed. The self-learning starts automatically. (Modified from [9])

In the original Active model the sensor unit was bigger and it required an additional power supply unit. Newer Active+ has an upgraded, smaller and more sensitive multi-funtional sensor and no need for separate power supply unit, as the sensor is connected to and draws power straight from the driver. From the user point of view, after installing the complete luminaire, just switching the power on starts the full functionality of the concept. No programming or no external wiring apart from the mains cable are needed, so the whole installation is intended to be plug&play.

Active+ is designed for refurbishment projects or new installations. For instance offices, corridors and open plan areas such as classrooms are suitable. Meeting rooms and other spaces, where there is a need for changeable scenes or lighting scenarios for varying situations, may be challenging for Active+.

After the initial powering up of the luminaire, the learning period of 60 - 100 hours of pre-defined fixed light output levels starts, and after that Active+ begins to use energy-saving features automatically. The length of the learning period depends on the occupancy and sensor readings of Active+. During the learning period the luminaire gathers samples from the sensor data, and it decides if it is alone in the room or surrounded by other luminaires. In addition, it detects if there is enough external light affecting it, such as daylight. The process chart of the operation is presented in Figure 5.

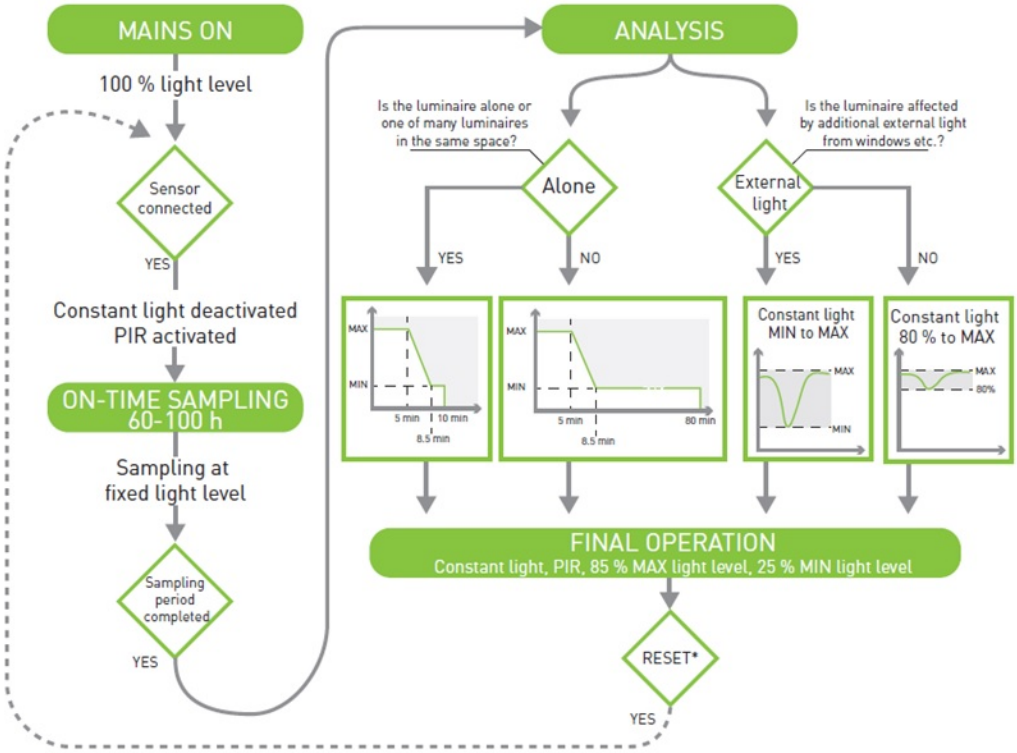

Figure 5 – The process chart of the Active+ operation. In the self-learning period during the sampling time of 60-100 hours, the luminaire analyses the amount of other luminaires in the room and the external light affecting it. The whole process can be reset by the user. [9]

If Active+ senses that it is alone in the room such as a private office, after the absence detection of the PIR sensor and the following preset transition time, it dims down and holds the dimmed light level only for a short time before switching off to maximise energy savings. In case of Active+ deciding that it is one of multiple luminaires in the room, the dimmed level after absence is left on for longer time. This way the lighting comfort is improved in e.g. open plan offices, when the luminaires do not switch themselves constantly but keep an ambient light level instead.

Besides the occupancy detection, energy is also saved by the daylight harvesting mode, which dims the light output when the light sensor detects enough daylight. During the learning process Active+ makes the evaluation if there is enough daylight or external light during the workdays for it to be able to dim the light source and achieve energy savings. If that is the case, when the luminaire is e.g. near a window, the dimming dynamic is set from a low minimum level to maximum light level to benefit from the daylight harvesting. If there is not enough external light, the lower boundary of dimming range is raised to 80%, so the luminaires will not start waving the light levels noticeably because of temporary reflections or artificial light distractions hitting the sensor.

Maximum light level is set also automatically, determined by light sensor measurements and the constant lumen output (CLO) setting. CLO sets the initial light output lower to create approximately 85% of the illuminance level that full maximum power of the driver would create in the operating environment, to prevent over-illumination of new luminaires. Lighting designers usually calculate a little higher initial illuminance levels than would be needed because the lumen depreciation is taken into account. In solutions with CLO such as Active+, when the light level starts to decrease because of the drop in luminous flux of the LED module, driver increases its output power closer to the maximum specification to compensate this. CLO is automatic in the Active+, as the light output is constantly adapted to match the designed light level set in the learning process and measured by the sensor.

If the user wants, the luminaire can be reset by covering the light sensor completely for a period of one minute or more while the luminaire is switched on. The luminaires connected to one electrical circuitry can also be all simultaneously reset by switching the mains voltage for that circuitry in successive on/off sequences. Five pulses with the distinct lengths stated in user manual reset all the luminaires in the circuitry. After the reset, the learning period of Active+ starts again.

Although the most important funtionality is configured through a self-learning process, Active+ has an option for the users to adjust the parameters themselves. This happens with the help of an Android smartphone application, which has a wide scale of options available, e.g. light levels and fade times. The commands are signalled to the Active+ via brief series of high-frequency flashes of smartphone camera flash. The light sensor recognises the pulses and sets the desired parameters. This feature is mainly intended for the maintenance staff, not the end users, but the personal adjustment of a luminare above the workdesk is possible in this way.

The concept is intended to offer a replacement for a traditional on/off switching luminaire, with the same installation effort. The additional energy saving is guaranteed though because the energy saving functions are automatic and always operating without user contribution. Initialisation does not need any configuration from the user either, but the smartphone application enables customisation. Active+ solution and its features are compared to other products on the market in chapter 4.

3.2 NightDim

NightDim is a solution that adds new functionality to outdoor lighting compared to switching luminaires. The main targets according to Helvar are improved energy efficiency and easily changeable scenes. [10]

Installed inside the luminaire, the nightDim DALI LED driver with pre-installed specific software registers when the mains voltage is switched on and off. 30 Watt nightDim driver can be seen in Figure 6. It can be controlled with pulses in the mains voltage to activate pre-defined scenes in the driver. No additional hardware is thus needed, because operating voltage is prerequisite for the luminaires to function.

Figure 6 – Helvar LC1x30-E-DA-nDim 1x30W nightDim LED driver. [10]

Each setting is communicated and set to the driver with a control pulse of specific length and a common verification pulse afterwards. The recalled scene is valid until a new scene is chosen. Setting the scenes to the luminaires can be the responsibility of people such as facility maintenance staff, apartment owners or municipality engineers, and controlling the nightDim should be simple enough for everyone to use. Only mains rated switch is needed, as seen in Figure 7. If there is not an actual switch available, an existing circuit breaker can also be used.

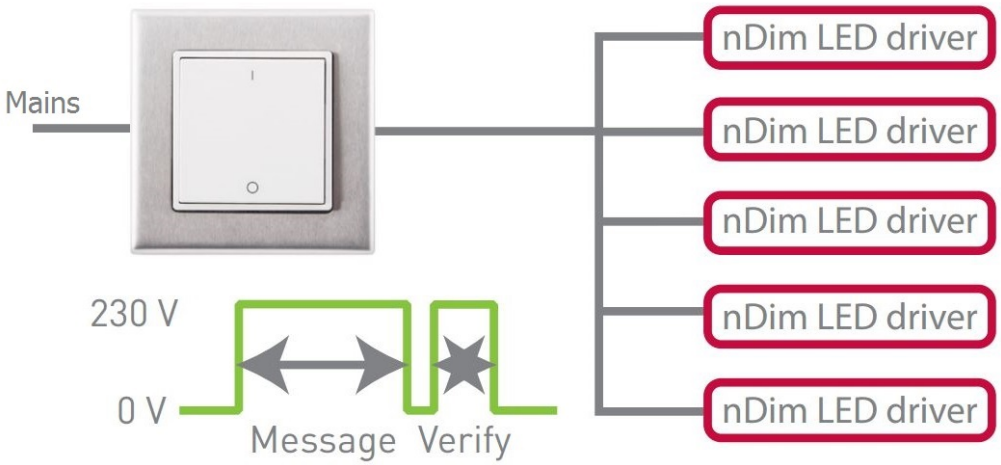

Figure 7 – Connecting and controlling the nightDim solution. Only mains rated switch is needed to switch the mains voltage on and off. Prespecified command pulses and a verifying pulse afterwards set the desired scenes to the driver. [10]

One method that some competitors use when controlling the products is the wireless communication, which is still relatively error-prone technology compared to existing cables. Another one is power line communications (PLC) i.e. modulating the control signal on top of the mains voltage and then demodulating it in the luminaire [19]. Both wireless and PLC technologies need designated transmitters and receivers in both ends, unlike nightDim.

As informed in the user manual, pre-defined scenes include static scenes with fixed light output levels of 100%, 50% or 25%. Besides fixed levels, a dynamic setup is offered also, illustrated in Figure 8. That includes a dimmed period in the middle of the powered-on period, set to 50% output level. The length of that period can be set to six, seven or eight hours. Fade time between full and dimmed level is 30 minutes, which ensures that the dimming transition is slow enough for nearby people not to notice or be disturbed. [10]

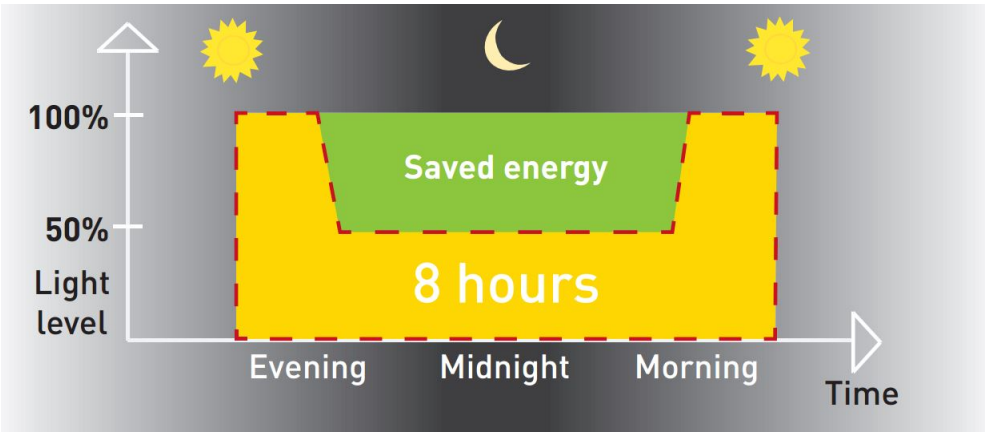

Figure 8 – Example of a nightDim dynamic saving mode. The adjustable dimming period is in the middle of the night. [10]

NightDim does not have a built-in real time clock, only virtual time clock to enable the scheduling of the dimming periods in the designed way. Two first nights are left on 100% as the driver calculates the average length of the nighttime. It is measured every night from the point when the lights are switched on to the point when they are switched off and then averaged with previous nights. Dimmed period is then scheduled to be in the middle of the period when the lighting is switched on. Dimmed period can also be adjusted one or two hours forwards or backwards from the calculated middle position.

Only thing needed for the setting of the scenes is a mains-rated switch or a circuit breaker. Manual switch, dusk sensor, timer or similar can be used to control when the luminaires are switched on in the evening and when they are powered down in the morning. Intention is that the customers continue to use the system that they choose or already have been using.

Another energy saving feature is CLO as with Active+ also. This time when there are no sensors, the luminaire manufacturer sets a scheduled increase in the output power of the driver according to the estimation of lumen depreciation of the luminaire. This prevents the over-illumination in the beginning and ensures constant light output throughout the life cycle of the luminaire.

NightDim concept has been launched in 2015 with 20W, 30W and 70W LED drivers with nightDim functionality. Drivers can be connected with DALI products and parameters set also with DALI commands. Stand-alone functionality is achieved with only mains on/off sequences however.

Applications for nightDim could be found in e.g. parks, gardens, streets and refurbishment projects. As a stand-alone concept, nightDim offers energy saving functions through simple installation and usability. Comparison to other stand-alone solutions is presented in chapter 4.

3.3 Select the Weather

Select the Weather is a simple human centric lighting solution. It offers the user an option to choose lighting between different static scenes and a dynamically changing scene that simulates the natural weather. [11]

Select the Weather concept makes use of the new DALI Type 8 drivers that are able to adjust the correlated colour temperature (CCT) of the light. This technology is often referred to as "tunable white". As the technical specifications state, the drivers have two different channels to control the currents of two LED modules. One channel is intended for the warm white LED module and the other one for the cold white LED module, and the balance between them corresponds to the overall colour temperature of the light. One driver has still just one address in the DALI subnet.

Select the Weather is a concept created to bring value to customers not only by energy efficiency, but with human centric lighting design too. This ideology has the

focus on the physiological effects of light, on the well-being and productivity of the people. The modern research has proven the existence of new kind of photoreceptor cells, so-called intrinsically photosensitive retinal ganglion cells (ipRGC). These cells are sensitive to light, and they affect the hormonal balance and thus the circadian rhytm of the human when stimulated by the light. The ipRGC cells are most sensitive to light with a wavelength of approximately 480 nm, which is in the region of blue visible light. The research has shown that the stimulus of blue light seems to suppress the production of sleep hormone melatonin in human the most. [20] These foundings have driven the researchers to many studies, where positive effects of e.g. increased illuminance [21] and higher colour temperature [22] on work productivity have been found. The human centric lighting has been estimated to have its own benefits to the society, but more research is still needed to prove them [23].

The concept consists of the DALI LED driver with the preset Select the Weather scenes, DALI cables, one DALI power supply for the connected devices and a specifically designed control panel, seen in Figure 9. The DALI power supply, iDim Solo unit, is installed in at least one of the luminaires in each system. Presence detection can be enabled optionally by connecting a DALI compatible PIR sensor to the Select the Weather circuitry. In the drivers there are preset scenes for the occupancy sensing feature preprogrammed, including the dimmed transition scene, lights off scene and returning to last dimming and colour setting. The presence detector operates thus in a plug&play principle as well.

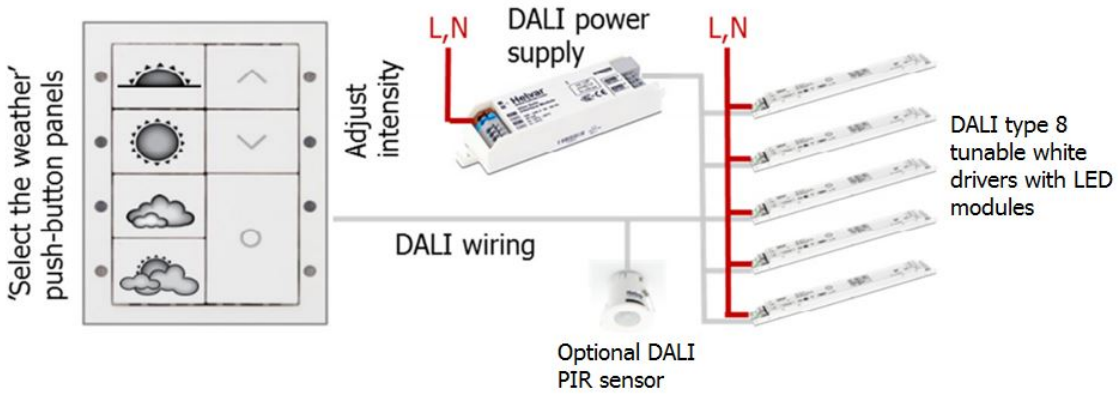

Figure 9 – Connection diagram of the Select the Weather solution. The DALI power supply is installed inside one of the luminaires, and the drivers, button panels and any optional PIR sensors are connected with DALI wiring. (Modified from [11])

No configuration or programming of the products is required on site, everything is ready to use after the physical installation. Powering on to the last dimming level and colour temperature is set as a default function.

The connected luminaires can be switched on and off and dimmed from the push-button panel. There are also four preset scenes the user is able to choose from, presented in Figure 10, by pushing the corresponding button on the control panel. The panel has also an infrared sensor, so the scene selection and switching/dimming

is possible with an infrared remote controller. The scenes are designed to activate various physiological effects of the light on the users in the room. First scene is *calm down*, which selects warm white light with low CCT and 80% intensity for the light output. *Energise* turns the light to cool white with high CCT and full intensity, aiming for suppressing the melatonin production. *Concentrate* offers intermediate colour temperature with 50% intensity.

	EFFECT	WHEN TO USE	COLOR TEMPERATURE	LIGHT OUTPUT
	Calm down	High stress period	Warm	80 %
	Energise	Early morning	Cool	100 %
	Concentrate	Thinking process & presentation	Intermediate	50 %
	Stay alert	Normal daily work	Changing naturally	90 %

Figure 10 – The four preset scenes of the Select the Weather solution. [11]

The fourth scene, *stay alert*, sets the CCT to change automatically with a random sequence, while the intensity is set to 90%. This scene simulates the natural changes that happen in the lighting environment outside, caused by moving clouds, direct sunshine, rain etc. The colour temperature in this scene is chosen randomly each time from four values, which are calculated between the minimum and maximum CCT values, from warm to cool white. The adjustable temperature range depends on the LED modules used in the luminaire, which can be specified according to the customer needs. Common values could be e.g. warm white module of 3000 K and cold white module of 6500 K. The photometric characteristics such as colour rendering index (CRI) and colour consistency depend on the chosen modules too. Fade times between the temperatures in the dynamic mode vary randomly between four values: 2 min, 5 min, 10 min and 30 min. The change of the temperatures should hence be as smooth and vivid as possible, but not distracting.

Colour temperatures are calculated by the driver factory presets and cannot be changed, but the intensity of the light can be adjusted with buttons. Intensity level cannot be stored under the aforementioned four preset scene settings however. If no control panel is installed the dynamic weather scene, *stay alert*, is always on. As standard DALI devices, the panel and luminaires can be included in any DALI subnet. The scenes 5-13 are left uninitialised in the drivers and they are possible to be programmed freely with DALI as desired.

As earlier mentioned, Select the Weather offers tunable white technology in a stand-alone solution that does not require any programming or configuration before use. Select the Weather is compared with other stand-alone solutions in chapter 4.

3.4 Summary

The three Helvar stand-alone concepts, Active+, nightDim and Select the Weather are designed to offer various functions in commercial and outdoor lighting with simple initialisation and usability. As stand-alone solutions, they operate in the fully functionable way whether there are only one or dozens of luminaires with aforementioned Helvar products installed. No programming or commissioning is needed before use.

Active+ is a new self-learning luminaire concept. A multi-funtional sensor and a preprogrammed driver are installed inside a luminaire, which is then installed like a traditional on/off switching luminaire. Once the mains cable is connected and the power switched on, Active+ starts to learn about its environment and the surrounding luminaires and external light affecting it. It optimises then its occupancy sensing and daylight dimming behaviour automatically according to the measurements made during the learning period. The normal operation is also completely automated, switching and dimming the light as the users come and go and external light is available. When adjustment is desired, the user can configure the parameters from the light levels to transition times with an smartphone application which flashes the commands to the light sensor with the built-in smartphone camera flash. Active+ enables energy saving features and visual comfort without requiring additional equipment, external wiring or initial programming.

NightDim is a stand-alone solution designed for cost-efficient outdoor lighting control. The nightDim driver has pre-programmed nighttime dimming schedules, from which the user can choose the most suitable with just switching distinct pulses of the mains voltage to the driver. Every adjustment option has its own predefined command pulse, so the configuration is possible with just a manual on/off switch or circuit breaker, enabling remote control of all the luminaires in the electrical circuit. The dimming period can be set to static dimmed level throughout the night, or then a dimmed period of 50 % light level in the middle of the night. NightDim enables driver integrated functionality, efficient scene setting and energy savings in the outdoor lighting.

Select the Weather brings the tunable white technology to a simple stand-alone solution, which is ready to operate immediately after physical installation. In addition to the luminaire, Select the Weather system makes use of the designated control panel for the user to be able to adjust the light intensity and select one of the pre-programmed human centric lighting scenes. "Calm down" scene has soft, warm white light, "energise" scene sets cold white light and high intensity, "concentrate" scene has intermediate CCT and 50% intensity, and the fourth, "stay alert" dynamic weather scene is programmed to change the colour temperature in a subtle, automated way to create a dynamic lighting environment.

4 Competing products on the market

In this chapter several products that advertise themselves as stand-alone solutions are introduced and analysed. All the information is based on the available marketing material, no products have been tested in this thesis. They all have both similar as well as varying features. As they differ in complexity, need for initial configuration and finally ability to operate on their own without additional infrastructure, it seems that different manufacturers use the term "stand-alone" in a quite wide scale of solutions. In the end of the chapter the solutions are compared in indoor and outdoor stand-alone lighting solution comparison charts.

4.1 Indoor stand-alone lighting solutions

4.1.1 Helvar iDim Basic

Helvar iDim Basic is a stand-alone solution for indoor luminaires. According to Helvar the greatest benefits are the ease of use, energy efficiency and plug&play operation. Helvar states that the solution is designed to be easy to install, use and integrate, providing intelligent and reliable operation to the end users. Specifications and material about iDim Basic can be found on the Helvar website. [24]

As stated in the brochure, iDim Basic is a luminaire-based control solution for fluorescent and LED luminaires in single room applications. There are six pre-defined modes programmed in iDim Basic for it to fit into any environment and operate suitably. It uses and is fully compatible with the DALI standard. Using the non-proprietary protocol does not limit the possibilities and allows iDim Basic to be connected with other DALI compatible products. The energy efficiency is guaranteed by several features such as presence detection and CLO by ambient light level measurements.

The components needed to build an iDim Basic luminaire are the iDim Sense sensor unit seen in Figure 11, iDim Solo interface module seen in Figure 12 and any DALI compatible ballast or driver with factory preprogrammed iDim Basic presets. Additional iDim remote controller is offered for controlling the luminaire and enabling the configuration of the parameters and setting the desired light levels. After the installation of the complete luminaire, the rotating mode selector on the iDim Sense sensor unit must be turned to the correct position according to the environment the luminaire is installed in.

It is possible to connect other DALI luminaires as slaves to iDim Basic luminaire with DALI cables, so that the luminaires of the whole room can be networked with iDim Basic. The luminaires can be grouped by connecting them in two distinct ports, so that e.g. the first group operates in constant light mode near the windows, according to the master iDim Sense light measurements, and the second group has an offset of +20% in lighting level. The amount of DALI ballasts or drivers to be

connected must be calculated so that the total current in the subnet does not exceed the capabilities of the power supply and in any case stays under 250 mA if there are no DALI Repeaters in use [15].

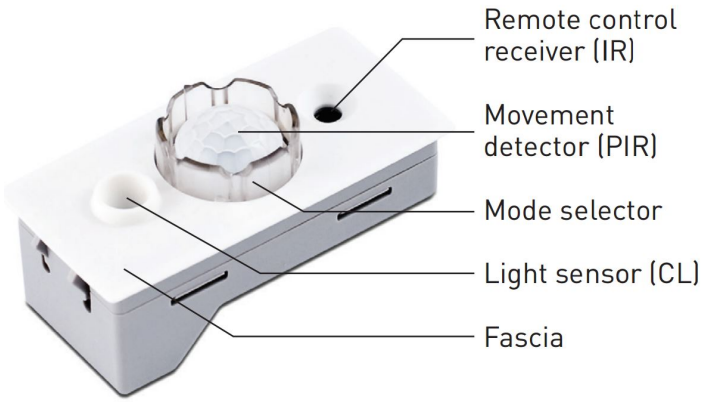

Figure 11 – Helvar iDim Sense multi-funtional sensor. [24]

The iDim Sense sensor unit is designed to be installed into the luminaire either in recessed way or by fitting an adapter to the louvre. There are two versions of the sensor, both of them can be used in the stand-alone solution, but the other one is also capable of operating as a DALI unit in a DALI subnet. IDim Sense has three sensors: PIR, photocell and infrared sensors. For occupancy sensing functionality, each mode has its own default delay times which can be also adjusted manually. There is also an optional clip-on PIR lens restrictor to limit the area that the sensor is sensing from. The photocell light sensor monitors the illuminance level under the luminaire and uses daylight harvesting to dim the luminaire when there is enough daylight coming in.

Infrared sensor receives commands from the remote controller. If the sensor unit faceplate is left visible in the installation into the luminaire, there are clip-on fascias available in different colours to match the exterior surface of the luminaire. PIR coverage can be extended by connecting additional iDim Sense sensors in the DALI terminals.

The iDim Solo interface module seen in Figure 12 is intended to be installed either inside or outside the luminaire. In addition to connectors to DALI cables, mains and iDim Sense, it has two switch&dim inputs. Switch&dim refers to technology, where the user can both switch the lighting on or off and optionally dim it by pushing the button for a short or then longer time. iDim Solo can act also as a DALI power supply on its own.

The iDim Basic has six pre-defined modes available: classroom, single office, open plan office, corridor hold, corridor link and meeting room/classroom. Each mode has its own parameters which are designed for the environment, e.g. open plan office has longer transition time with the dimmed lighting after absence is detected and corridor hold keeps the corridor lights on when at least one of the attached offices

is occupied. There are also four different pre-programmed scenes for each mode, changeable with the iDim remote controller. The desired light level must also be manually set with the remote to suit the installation environment. This ensures that along with the daylight dimming and CLO features the best lighting comfort and energy efficiency is achieved.

Figure 12 – Helvar iDim Solo interface module. [24]

When the user wants customised parameters, the advanced adjustment is done with the iDim Studio software with the remote controller attached to a PC with USB cable. By connecting switch&dim switches or DALI button panels the users can switch the iDim Basic products on and off or dim them, overriding the automatic operation until the next power down.

Compared to the original Active the iDim Basic solution offers more adjustability with the remote controller and iDim Studio software. Active+ compensates this with the mobile application though, with which all the essential parameters are free to be adjusted. While Active+ relies on fully automatic and individual operation, iDim Basic gives more possibilities to link luminaires and use remote controlling in the lighting system, enabling e.g. controllable meeting room implementations. In terms of components, the iDim Basic solution has the additional infrared sensor in the sensor unit and also a separate Solo unit, and the installation and configuring before use is not as simple as with the self-learning Active+.

4.1.2 Philips Actilume

Philips is a Dutch technology company with one primary division focused in professional lighting. Philips Actilume is a stand-alone solution for indoor lighting. Philips states that the solution can offer easy installation and significant energy savings with combined LED lighting and control compared to switching fluorescent lights. It switches the lights according to presence in the room and makes use of daylight

harvesting by dimming the lights when there is external light present. The lighting can additionally be controlled by a wall-mounted push-button, a pull switch or an infrared remote. Comprehensive applications guides and datasheets about Actilume can be found on Philips website. [25]

Actilume consists of the control device and the sensor module, which includes the PIR sensor, light sensor and infrared sensor. The control device and sensor module can be seen in Figure 13. All the changes to the system can be made with an infrared remote or optionally with a push-button on the sensor module. After the installation, before the actual use the appropriate mode has to be selected to match the installation environment. There are different pre-configured modes for office, corridor, toilet etc. Cell office mode is selected by default, but the user can select the mode between open office and cell office by pushing the button on the sensor module. Other modes need official infrared remote to be selected. The light level is set to create the illuminance of 600 lux on the surface under the luminaire, but that assumes the ceiling height to be 3 meters and the reflection factor of the surface under the sensor to be 0.3. For optimal operation, the light level must be calibrated to the situation by pressing the button on the sensor unit to start auto-calibration or optionally adjusting it with the remote.

Figure 13 – Philips Actilume DALI gen2 system with the control device and multisensor. [25]

After the initialisation, Actilume works as an independent luminaire with automated use, same as Active+ and iDim Basic. As stated in application guide, the switch-off delay is 15 minutes after the PIR sensor detects no more presence. Multiple luminaires can also be linked and connected to an Actilume luminaire, controlled as slaves with DALI signals. There are two slave outputs in Actilume, other one for luminaires near the windows and other further away. The luminaires away from windows are told to maintain a slightly higher light level. Up to two external PIR sensors can be optionally connected to the system so that the coverage extends to a larger area.

The newest Actilume DALI gen2 system has some improvements, e.g. raising the maximum number of connected luminaires from 11 to 25 over 4 groups, enabling networking several Actilume luminaires by parallel linking them and adding a pre-configured mode when linking Actilume into building management system (BMS). BMS connection needs a specific gateway, and according to Philips currently the sole gateway supplier to fully support Actilume is Loytec. When one connected driver fails and is replaced by a new one no re-commissioning is needed as the controller will program the new driver with the setting of the driver that has failed. Philips has released Actilume Color solution with separate outputs for luminaires with red, green and blue light, as well as Actilume Wireless for use with wireless sensors and control devices.

The system functionality is very similar to iDim Basic and much like Active+, but after the installation the suitable mode has to be chosen before optimal operation. Self-learning algorithms improve thus the ease of initialisation of Active+ solution. When configuring the parameters, Actilume needs the official Philips infrared remote, when with Active+ mobile phone is enough. Exception is the Actilume Wireless, with which the configuration can be made wirelessly with LCN8650/10 MultiOne configurator dongle with ZigBee wireless connection. As is the case with iDim Basic too, when comparing to Active+, the Actilume solution offers the feature to connect other luminaires as slaves when the situation is such that only one sensor and intelligent unit would be enough for the room.

4.1.3 Organic Response

Organic Response is an Australian company offering a solution for indoor luminaire stand-alone control. The system is based on distributed intelligence, as there is no centralised control. Organic Response is advertised as highly responsive, flexible and energy efficient system that improves also user comfort. They state that the system is simple and cost-effective to install and use, and the payback time is as low as three years. The solution should work effectively in e.g. schools, hospitals and offices according to them. Organic response offers documentation and guides about the solution on their website. [26]

Comparing the operating principle to the fishes in the nature, Organic Response relies on the distributed intelligence, meaning that every luminaire adapts and makes decisions according to the environment and the surrounding luminaires. The system can be used with any 1-10V or DALI compatible LED and fluorescent ballast/driver.

Organic Response solution includes a sensor node and a controller interface installed inside the luminaire, presented in Figure 14. The sensor node has a PIR motion sensor, infrared transmitter, infrared receiver, light sensor and status indicator LED, while a built-in microprocessor controls the operation. One node can control multiple luminaires, but it is not suggested, as the accuracy suffers. Optimal operation, as with Active+ too, is achieved with sensors in every luminaire. Sensor node can also be installed in its own housing if it does not fit into the e.g. pendant style luminaire.

Figure 14 – The Organic Response sensor node and controller interface to be installed inside the luminaire. [26]

Luminaires equipped with Organic Response act on their own, adapting to occupancy and ambient light. When a person enters the empty room and one sensor detects occupancy, the sensing luminaire sends infrared signal to the nearest luminaires, which receive it and send their own signal again to the next tier of adjacent luminaires. Each tier has its own dimming level preset a little lower than the previous one, so that the light output decreases in relation to the distance around the user. At the same time an occupancy information cloud is gathered and created from the sensor data. This is illustrated in Figure 15. This improves the visual comfort when entering dark or dim larger rooms, but on the other hand increases the energy consumption too when increasing the light also in the luminaires further away.

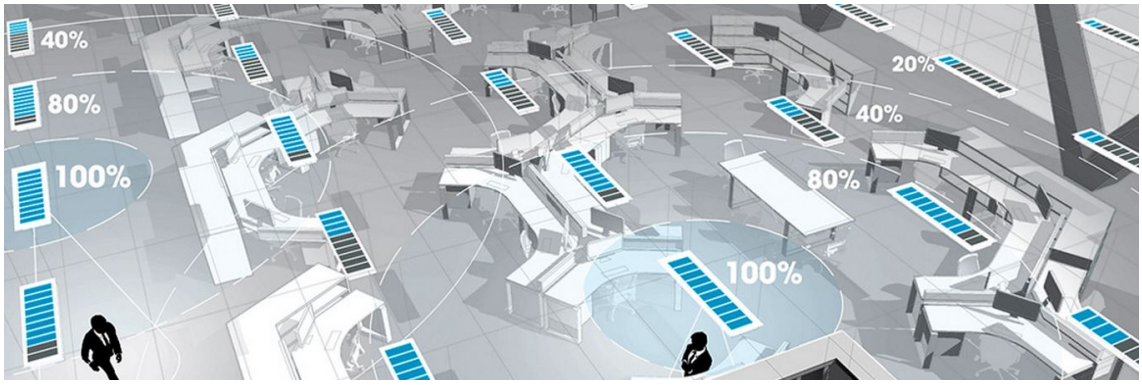

Figure 15 – An illustration of Organic Response gradual dimming algorithm. [26]

The infrared communication signal is reflected off the floor between the luminaires, and as the receiving and transmitting sectors of the infrared sensors are restricted, the signal reaches only the nearest luminaires with sensor nodes. When installing the system the distances are therefore suggested to be between one and three meters between luminaires and 2,7 m - 3,7 m between luminaires and the floor. In case of individual sensor node failure or malfunction, the luminaire switches itself to 0% or 100% depending on the fault, but the operation of the whole system should not be impaired.

The system is advertised to be completely plug&play capable, it is ready to operate right after installing it and connecting the mains. The preset configuration enables the luminaires to communicate with each other and dim automatically around the users according to the occupancy. The daylight dimming feature is disabled by default though, and the occupancy sensing behavior is designed for open floor use. When the users desire a possibility to configure and optimise the lighting, Organic Response has developed a smartphone application for iOS and Android to enable adjustments. Anyone without special training should be able to do the configuration, and different permissions can be given to e.g. end users and building managers. The signals from the application are delivered via directional infrared module, which is attached to the headphone connector in the smartphone. The module is then aimed at the desired sensor node when giving commands.

With the smartphone application, parameters such as minimum and maximum light levels, transition times and sensor sensitivity can be adjusted. If wanted, the luminaire can then be commanded to relay any adjustments made to all others luminaires too in the signal chain via infrared. Daylight harvesting according to the measurements of the light sensor is possible, but the light output of the luminaire must be first manually adjusted to preferred level and the daylight dimming mode enabled with the application after that. That is also required for the lumen maintenance feature to be able to maintain constant lumen output. Corridors can be linked to nearest zones with the smartphone application, as well as different zones programmed to behave differently. Although the default settings should be suitable for all-around use, there are over a dozen preset "personalities", meaning modes for occupancy sensing behavior to be selected with the smartphone application. User can also configure several scenes and the luminaires can be programmed to enter a preset scene in startup. When more integration is desired, the system can be also connected to audio/video (A/V) systems or BMS with an ethernet gateway.

In addition to the configuration of the scenes and light levels etc. also temporary control such as simple on/off and dimming controls are possible with the application. Organic Response offers also wireless battery-operated wall switches with on/off, dimming and scene selection functionality. Switches control the adjacent luminaires in the reach of its infrared signal, or then the commands can be relayed to control distinct zones, configured with the smartphone application.

The system adapts automatically to the changes in layout, as the luminaires communicate with each other via proximity-limited infrared signals. If a wall or partition is moved, the pathway for the signals change. In a case of unwanted barrier between two sensor nodes when the infrared signals cannot reach the receivers, a wired sensor node link can be used.

The idea of simple and efficient Organic Response solution is similar with Active+. Both are designed to be installed inside luminaire by the luminaire manufacturer and they are configured with a smartphone application. Organic Response has the advantage of communication happening between separate luminaires, while Active+ has the unique self-learning algorithms enabling more optimised plug&play operation.

4.1.4 Helvar freeDim / Fagerhult e-Sense Tune

Helvar freeDim is a wireless lighting control system for commercial use and personal lighting adjustment, utilising wireless protocols and DALI Type 8 standards. The system is intended for cellular offices, conference rooms or activity areas and can be combined with other types of control systems more suitable for large open plan offices. It was developed in cooperation with Swedish luminaire manufacturer Fagerhult, which sells the technology under the label e-Sense Tune. For clarity, the name freeDim is used in this thesis from now on. Helvar and Fagerhult state that freeDim is a decentralised plug&play stand-alone system. Some information about freeDim can be found on Fagerhult website [27], Helvar internal material has also been utilised.

The system consists of a master unit and a multi-functional sensor with PIR and light sensors to be installed inside freeDim equipped luminaire. The system can be reset if needed by pushing a button on the sensor. Master unit is connected with DALI cables to single one or then up to four DALI Type 8 LED drivers, but they will all act in the exactly same way. Other luminaires with so-called following units inside can be connected to the master unit wirelessly via 802.15.4 protocol similar to ZigBee. Typical system size is mentioned to be 1-6 luminaires per room, although several system can co-exist in the same area.

Personal control is enabled with a smartphone application designed for iOS and Android, seen in Figure 16. The application communicates with the luminaires via low-energy Bluetooth Smart protocol. Firmware of the controller units can also be updated wirelessly with the smartphone application. One user at a time can affect the light, but multiple user profiles can be stored in one master unit, secured by PIN codes. The data transmission is restricted locally, and the connection to the freeDim controls should not be possible outside of the building or the room.

Figure 16 – Fagerhult e-Sense Tune smartphone application on iOS and Android for controlling the solution. [27]

Once connected to a smartphone, the user can set a preferred lighting scene to be set up everytime he or she enters the room and the phone is detected via Bluetooth. Presence detection with smartphone enhances also the occupancy detection, giving more accurate real-time data when people are in the room and when not. Smartphone control ensures that the controlling device is usually at hand and no extra devices are needed. The Bluetooth must be enabled in the phone however, increasing the battery consumption. If the controlling smartphone is left home or not paired, the preset default scene is set when presence is detected by PIR sensor.

User is able to control the intensity and colour temperature of each connected luminaire with the smartphone application. There are also four preset scenes available: *activate, focus, adapt and mimic*, implementing the human centric lighting effects as discussed in chapter 3.3. *Activate* scene sets cool white light for energising. *Focus* is a warm, dimmed lighting scene for e.g. personal talks and concentration. *Adapt* is the daylight harvesting mode, with which the light level is adapted according to the ambient light. *Mimic* is designed to mimic the daylight and change the intensity and colour temperature throughout the day. The light in the morning has a low intensity and warm colour temperature, it turns colder and more intensive towards noon and then again softens to warm dim light in the evening. In addition to the preset scenes, user can create two own personal lighting scenes to choose from.

To further extend the functionality of freeDim, with optional gateway it is possible to connect one or multiple systems to e.g. router to enable centralised management, fault reporting, energy consumption analysis, BMS integration etc. While not offering self-learning or install&forget mentality, freeDim has its strengths in personal adjustment of lighting, utilising wireless technology and tunable white LED lighting.

4.1.5 Tridonic SMART sensors

Headquartered in Austria, Tridonic is a lighting components and control systems manufacturer. They offer SMART sensors which have ambient light sensors and occupancy sensors available in the model range. They are intended to be installed either inside or on the luminaire or then clipping them onto the fluorescent tubes. Although not clearly advertised as stand-alone concepts, the functionality is quite similar to the other sensor-in-luminaire solutions. Information about SMART sensors is available on Tridonic website. [28]

There are sensors available to cover installations with mounting height of 2-5 meters or 5-10 meters. The SMART sensor models with the most features have occupancy detection, daylight dimming and infrared remote controlling capabilities. The sensors are compatible only with specific DALI capable Tridonic fluorescent lamp ballasts with a SMART connector for the sensor. This enables the similar connection as with Active+ also, where the sensor is powered from the ballast itself. Two ballasts can optionally be connected to one sensor unit at the same time with an extension cable.

The SMART sensors can utilise the Tridonic corridorFUNCTION feature, controlling the behaviour of occupancy and daylight sensing. Either the PIR sensor in some SMART sensor units or external relay-type motion sensor can be used, light sensor however is included in all SMART sensor models. The functionality is very similar to other solutions compared in this chapter, and there are certain default parameters for e.g. fade times, transition times and absence light levels preprogrammed. Tridonic offers four different versions of the 5DPI and 10DPI SMART sensors (10DPI presented in Figure 17), one without any and three with preprogrammed corridorFUNCTION profiles. In practice these mean different switch-off delays after the light has been dimmed down due to the absence: 1 minute, 30 minutes or then the never-off mode, keeping the the minimum light level indefinitely.

Figure 17 – Tridonic 10DPI 19fe SMART sensor unit with ambient light sensor, motion detector and infrared sensor. [28]

Daylight dimming setpoint has a certain factory default value, but it must still be manually calibrated to achieve the desired illuminance on specific site. This can be done by pressing a button on the sensor, using an optional infrared remote or configuring it with DALI commands. While supporting DALI standard, the driver and the sensor can be freely configured with DALI programming, although then the system can not be considered stand-alone anymore. Also switch&dim switches can be used to adjust the light level temporarily.

Tridonic SMART sensor and driver combination offers energy saving features with similarly minimal initialisation as with Actilume and iDim Basic too. The difference is that the corridorFUNCTION behaviour parameters are fixed in each sensor version and configurable only via DALI programming with suitable interface and software. The available never-off mode with light intensity never dropping below a minimum level can also be achieved with Active+ by adjusting its settings with the smartphone application.

4.1.6 Schneider Electric and Lutron stand-alone components

Schneider Electric and Lutron are companies manufacturing electrical components for lighting and automation. They offer also stand-alone lighting control components. These are no ready full-scale systems, but with different stand-alone components, energy savings can be reached. There are also numerous other companies in the electric industry that manufacture similar components, as they are common building blocks of lighting control systems. Schneider and Lutron were chosen as examples in the comparison, as they advertise stand-alone lighting control components on their websites. [29] [30] The functions of the control are based on three parameters, Schneider states:

- Time: timing devices, e.g. staircases
- Light intensity: light sensors
- Presence: occupancy sensors and movement detectors (example in Figure 18), major energy savings possible in outdoor applications.

Figure 18 – Schneider Argus 220 movement detector. [29]

On the website it is mentioned that in advanced office and indoor applications, heating and ventilation can also be adjusted with presence sensor data. There is often also a light sensor integrated with PIR sensor so the light is not switched on during the bright daytime. Combining these functions is common and it leads usually to efficient operation of lighting.

Despite stand-alone operation during the normal use, these components are first installed in recessed or mounted way outside the luminaires, and cabling has to be taken care of. They have a default configuration done in the factory, and most of the parameters can be optionally adjusted with a potentiometer. While relatively simple products, the simplicity of installation and intelligence of these solutions cannot match Active+ however.

Schneider offers also Connect product family of wireless switches, dimmers, transmitters and receivers. With these the user can implement a desired system to switch appliances and dim lights without installing complex cablings. Connecting the products is done by pushing sync buttons on both the transmitting and receiving device. For any more complex functions, the system can be programmed with PC and wireless dongle to support e.g. different scenes and one button to switch off all the lights. The Argus 220 PIR sensor is also offered as a wireless Connect version to be linked to the switches. [31]

Lutron offers Energi TriPak system with Rania Wireless switches and Radio Powr Savr wireless sensors for the user to build a wireless control network. A picture of Powr Savr sensor can be seen in Figure 19. There are occupancy, vacancy and light sensors available, all synced by pushing corresponding buttons. One sensor can be linked with multiple switches. Parameters of the sensors can be adjusted locally with push buttons, but the default settings should be sufficient for most environments. Lutron sells also dimming receiver modules to be connected to their own EcoSystem family or generic 0-10V ballasts and drivers, wireless relay box to control other appliances and a wireless dry contact closure output (CCO) box that can be connected to e.g. heating, ventilation and air conditioning (HVAC) system or BMS. [30]

Figure 19 – Lutron Powr Savr wireless occupancy/vacancy sensor. [30]

For the most stand-alone operation, many manufacturers with Schneider and Lutron among others offer sensors that are integrated into switches and dimmers and designed to fit standard wall sockets. Installation is simple and they are ready to use without programming. Buttons and potentiometers enable basic configuration if desired. [32, 33] This solution restricts the position of the sensor as it has to be placed into a wall socket, which is rarely the optimal position.

Installing external sensors requires less effort with Lutron wireless products compared to wired stand-alone components, but the functionality is very similar. Although enabling a customisable system with user control by switches and dimmers, these Lutron components require still more complex installation and initialisation before use than Active+.

4.1.7 Digital Lumens Digital Light Agents

Digital Lumens is a US company offering intelligent LED lighting solutions. Their Digital Light Agent (DLA) product family consists of control devices that according to them turn any luminaire into an intelligent one. Digital Lumens has developed a control software called LightRules, which operates wirelessly, allowing the user to supervise and manage the whole lighting system at once. DLA devices enable the connection of any luminaire into the LightRules control family. Introduction to the product family, specification sheets and diagrams can be found on their website. [34]

Digital Lumens advertise Digital Light Agents as stand-alone lighting control solutions. They specify that DLA products are components equipped with PIR sensor, light sensor, full-range dimming capability and wireless receiver and transmitter. They collect the data from the operation of the luminaire, e.g. energy use, presence detection data etc. According to Digital Lumens, the energy consumption can be reduced significantly with DLA products.

The DLA product family include different models suitable for installation e.g. inside the luminaire, recessed or then surface-mounted on the ceiling or a junction box. DLA-I which is to be installed inside the luminaire can be seen in Figure 20. Digital Light Agents use DALI and up to 4 drivers can be connected to one DLA device. In case of luminaires with 0-10V controllable drivers, Digital Lumens offer adapters to convert the DALI signal to 0-10V, intended to use either with one luminaire or the whole circuit.

Figure 20 – Digital Lumens DLA-I. [34]

The main point of integrated DLA products is to bring wireless sensing and control to any luminaire without exterior control cabling. The LightRules software enables the adjustment of the luminaire behavior depending on the time and sensor data. Though advertised as stand-alone control, the system can not be considered as stand-alone solution according to the criteria of this thesis, as the LightRules network is required to commission the luminaires with Digital Light Agents. Setting up the LightRules infrastructure requires a network switch, LightRules Appliance and

Lighting Gateways. This is demonstrated in Figure 21. As they lack the stand-alone or plug&play functionality, DLA products and LightRules network are more likely to compete with centralised programmable DALI lighting control system. While offering wireless sensors, monitoring and management of the system, the amount of initial costs because of infrastructure components needed makes it probably better suited for larger projects than small renovations.

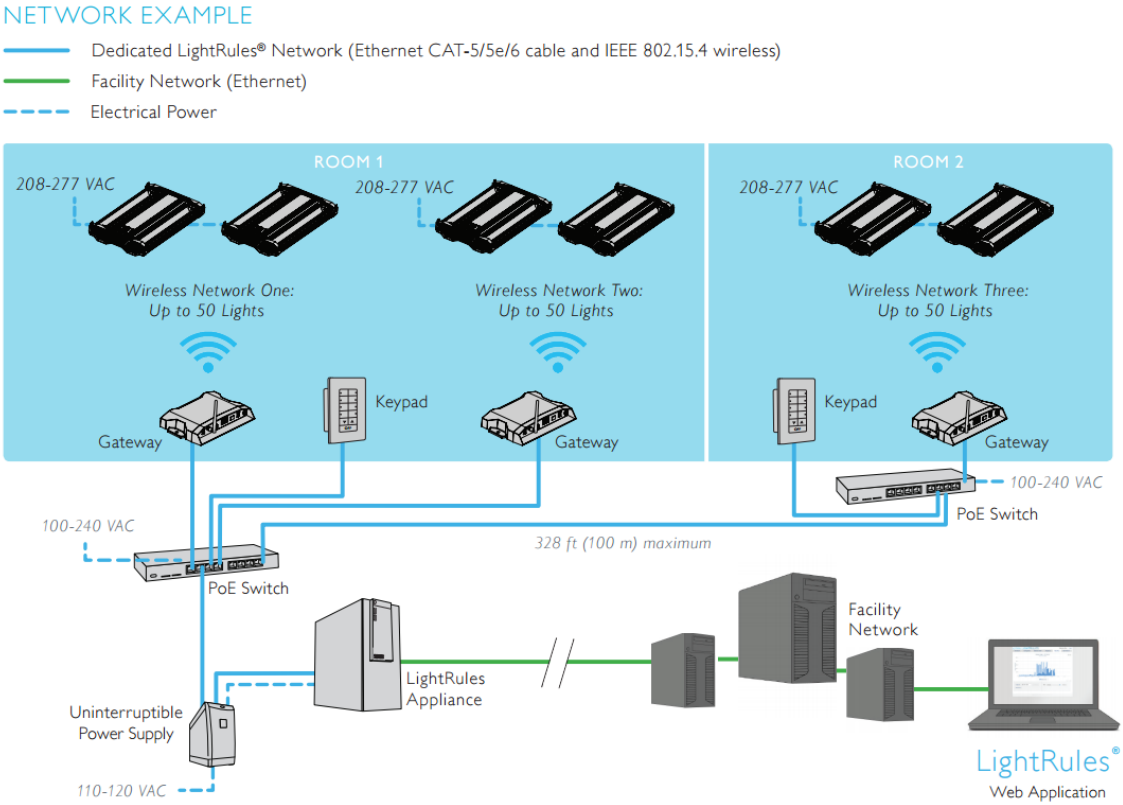

Figure 21 – Digital Lumens LightRules connection chart, which illustrates the need for building the wireless network infrastructure. [34]

4.1.8 Tridonic ready2mains

Tridonic ready2mains is based on the power line communications technology mentioned in chapter 3.2, meaning that the LED drivers can be dimmed and controlled directly via the mains without the need for any additional cabling. This technology is used by several companies in both indoor and outdoor solutions too, e.g. Osram has implemented it in Street Light Control (SLC) system [35]. Ready2mains technology is introduced on Tridonic website. [36]

Tridonic advertises that with ready2mains the luminaire manufacturers can configure the luminaires with ready2mains programmer by using only the mains connection before delivering them. In the installation site no control cables are needed and thus

costs are reduced. Tridonic states that the technology enables cost-effective solutions and easy refurbishments.

The dimming signal is carried in digital form on top of the mains AC signal as illustrated in Figure 22, and conventional push-buttons can be used as control units to dim the luminaires without any control cables. However, this requires a ready2mains gateway and suitable Tridonic LED drivers to create and interpret the digital signal in the mains circuitry.

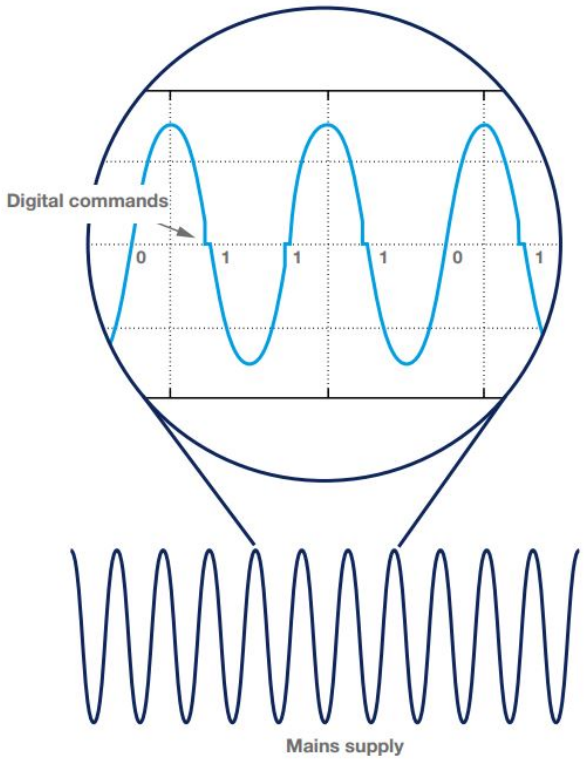

Figure 22 – Tridonic ready2mains phase-cuts on the mains signal. [36]

While being a competitive solution for enabling push-button dimming capability in refurbishment rooms and buildings, an additional gateway is always required besides the suitable switches. Therefore ready2mains infrastructure can not be considered stand-alone solution, at least on the terms defined in this thesis.

4.2 Outdoor stand-alone lighting solutions

4.2.1 BEGA Connection box 636 and Power changeover switch 868

BEGA is a German luminaire manufacturer, offering indoor and outdoor luminaires. Their Connection box 636 and Power changeover switch 868 seen in Figure 23 use 1-10V standard to control the dimming of the compatible luminaire. Bega offers datasheets and instructions for use on their website. [37] The only notable difference is that the power changeover switch is designed also for retrofitting and it has a higher IP rating. There is a self-learning algorithm in the software, like in nightDim, to detect the length of the night from the switch on and switch off points measuring the time between. After that, they calculate the midpoint and dim the lighting to 50% around it.

Figure 23 – BEGA connection box 636 and power changeover switch 868. [37]

Normal length of the dimming period is 6 hours, starting three hours before and ending 3 hours after the midpoint. This period can be adjusted 0.5, 1, 1.5 and 2 hours longer to both directions, so a total of 6-10 hours.

Controlling is done locally with a potentiometer, so there is no remote control. Default setting is test mode, so the suitable setting must be set manually before use. Otherwise the functionality is very similar to nightDim, but it lacks the remote adjustment and static dimming levels. The two products are also mainly intended to be used with BEGA LED luminaires, but as they use a non-proprietary standard they should operate normally with any 1-10V controllable luminaire.

4.2.2 Schréder Owlet

Schréder Group consists of 48 companies worldwide and they are specialised in outdoor lighting solutions. Schréder has Owlet smart solution family for the control of outdoor lighting. Optimal use is achieved with wireless mesh networking and communication via ZigBee protocol, but they are capable of being used also as a stand-alone solution. Schréder offers material about their Owlet solutions on their website. [38]

Key benefits that are advertised include low initial investment, fast payback, energy savings and easy installation. For the stand-alone functionality, the luminaire is fitted with a control unit. Photocell controllers have their own light sensor, and they work as a plug&play solution without the need for configuration. Separate control modules are designed to be installed inside the luminaires, and external sensors can be connected to them, e.g. motion detection sensors are available, although they operate only after commissioning of the device.

Schréder offers two Owlet photocell units, LuCo-PN (Lumen controller photocell NEMA) and LuCo-PD (Lumen controller photocell dimming, seen in Figure 24). Attached to the luminaire, they are both nodes capable of communicating wirelessly with a segment controller. Forming a mesh network, they take commands and send error signals. They also measure and collect electrical data during the operation. The wireless operation needs commissioning and external segment controller though, so it can not be regarded as a stand-alone solution.

Figure 24 – Schréder Owlet LuCo-PD to be attached to the luminaire. [38]

However, if there is no radio frequency network and no commissioning done, photocell unit works as light sensor for the luminaire and switches it on and off according to the external light level. LuCo-PN is connected to the luminaire via NEMA (National Electrical Manufacturers Association) twist-connector. LuCo-PD is the same as LuCo-PN, but it has the ability to dim with DALI or 0-10V signal and it has built-in CLO and virtual power output (VPO) modes. Virtual power output gives the option to remotely adjust the luminaire to operate on a decreased wattage, if the maximum power is too high for the optimal illumance level. As a stand-alone device without commissioning or the network, it works only as a switching photocell controller however.

LuCo-AD (Autonomous lumen controller with dimming) and LuCo-NX (Next generation lumen controller) are control modules to be installed inside the luminaires and they have almost the same functionality apart from the photocell sensor. Both have the ability to be controlled by the wireless network and an external light or motion sensor can be connected to the devices. The sensor status signals can then be sent via the wireless network. Both devices have CLO and VPO built in. LuCo-AD and LuCo-NX can be wirelessly configured to different dimming profiles triggered by timer or sensors.

LuCo-NX does additionally monitoring on its operation, including mains voltage, current, power factor, burning hours and cumulative energy consumption of the connected lamp/LED driver assembly. This data and error messages can be sent to the network wirelessly. There is also a built-in astronomical clock to help with the adaptation of dimming profiles or switching times to different seasons. Almost all of these functions require wireless network or commissioning however, and as a stand-alone devices the functionality is limited. LuCo-AD and LuCo-NX set the light level to 100% without commissioning, unless there is a light sensor connected, then they switch on and off according to the sensor.

Without commissioning and configuration the Owlet devices offer limited funtionality, and no information about self-configuration of the stand-alone solutions is presented on the website. Schréder advertises however that they offer turnkey solutions, so when customer decides to procure luminaires with Owlet solutions, Schréder field application engineers commission and configure the luminaires as desired. After that, the CLO, astronomical clock, daylight and motion sensor functionality as well as user-defined 5-level dimming profile is enabled. The operation can not be adjusted by user without professional programming however.

Schréder Owlet solutions offer many energy-saving options for outdoor luminaires. The products offer fairly limited features without the commissioning however, so even moderate stand-alone funtionality requires professional programming. The main advantages lie in the wireless communications. Photocell sensor and an astronomical clock are extra features compared to nightDim, but the Owlet system lacks the possibility to use most of its sophisticated functions as a pure stand-alone solution.

4.2.3 Philips Dynadimmer

For outdoor applications Philips has the Dynadimmer solution which is a stand-alone controller for individual luminaires with 1-10V drivers. Normal and separated or safety extra-low voltage (SELV) models are currently offered. Seen in Figure 25, Dynadimmer is installed inside the luminaire and requires no control signal wire. Intended especially for residential, roadway, parking and industrial applications, the main benefits are advertised to be reduced energy consumption and ease of use. Documentation about Dynadimmer products is presented on Philips website. [39]

Figure 25 – Philips Dynadimmer and Dynadimmer SELV modules. [39]

Dynadimmer enables the setting of up to five different dimming levels and five time periods. Example of this is presented in Figure 26. The dimming schedule must be programmed with PC though, then uploaded to the Dynadimmer with the use of USB cable or official programmer device. Android application is in the development, enabling the user to adjust the parameters with smartphone or tablet and USB cable. There is no real time clock in the Dynadimmer, the middle point is calculated in the same way as with nightDim and BEGA boxes. Dynadimmer can control multiple drivers, the dimming range will be limited however.

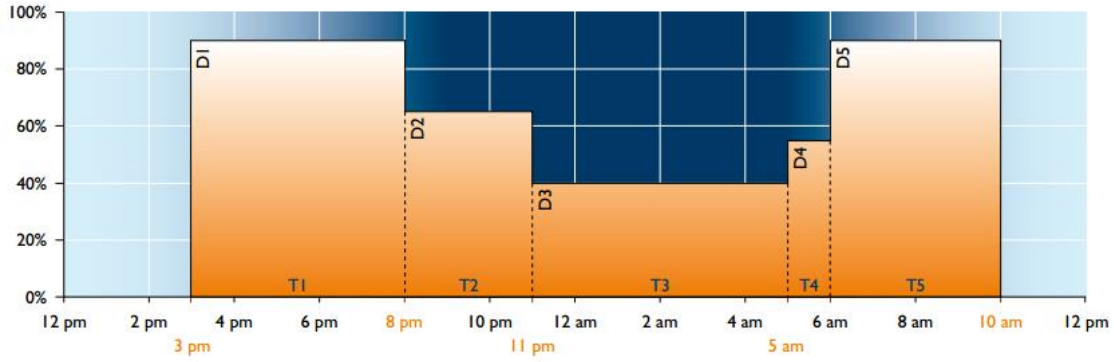

Figure 26 – Example of programmed Dynadimmer dimming levels and steps during the night. [39]

Dynadimmer is very similar to nightDim, but with more options for dimming levels and time periods. There is no remote controlling though, and the additional Dynadimmer module must be installed inside the luminaire. There can be one schedule pre-programmed when Dynadimmer is delivered to the customer, but the adjustment of the dimming profile is more complicated afterwards.

4.2.4 Philips Xitanium and Osram 3DIM outdoor drivers

Philips LED drivers in Xitanium Programmable range have either Dynadimmer or Dynadimmer LITE capacity integrated, as well as other features such as CLO, adjustable startup fadetime and possibility to signal the end of lifetime of the LED module. Dynadimmer LITE has the same principle as Dynadimmer, but it supports only 1-step dimming compared to normal Dynadimmer 5-step dimming. [40]

Philips offers both 1-10V and DALI compatible Xitanium Programmable drivers. In addition to Dynadimmer, another possibility is to use LineSwitch technology, which needs a separate control line wired to the driver. Output level is switched between two preset levels back and forth depending on the voltage set to control line. These must be configured with PC before use. Dynadimmer dimming can also be overridden to set the light output to e.g. 100% in emergency situation by using LineSwitch.

Compared to nightDim, the Xitanium Programmable driver matches the simplicity of installation of nightDim offering even more functions. The configuration of the driver must be done locally with PC and MultiOne configurator tool however. [40]

Osram, which is a German competitor in the lighting business too, has very similar outdoor drivers on the market, the 2DIM, 3DIM and 4DIM drivers. In 3DIM range both fluorescent ballasts and LED drivers are available. They have integrated control technologies such as AstroDim and StepDim that that are practically identical with Dynadimmer and LineSwitch. 2DIM models are 1-10V controllable, the others use DALI, and only the LED drivers have CLO feature programmed. Configuration is done with PC and interface module. [41]

4.2.5 Tvilight NightSky

Tvilight is a Dutch company offering solutions for implementing intelligent outdoor lighting control. Their product called Nightsky is a stand-alone control device featuring built-in astronomical clock, suitable for many outdoor applications, such as roadway lighting, industrial zones, residential areas, campuses, parks and tunnels. Tvilight advertises significant savings in predictable manner with NightSky. Documentation about NightSky can be found on Tvilight website. [42]

With the real time clock and relay the adaptive lighting control is possible without photocell. Astronomical clock helps NightSky to adapt to the local sunset/sunrise times, winter/summer seasons and weekday/weekend profiles based on the geographical location, remembering those throughout the year. NightSky can control both conventional and LED luminaires – as long as a dimmable ballast/ driver (0-10V or DALI) is used. Built-in high performance relay enables turning on/ off any lamp up to 400W, including traditional lamps that are not suitable for dimming.

Physically NightSky functionality is programmed inside a compact control module that is installed inside any luminaire. This should be possible by most contractors without special training, Tvilight states. Inside the luminaire the NightSky control module can switch and dim the luminaire, whereas in cabinet level it is possible to switch groups of luminaires on and off. Illustration of NightSky control module installation possibilities is presented in Figure 27. Control module can operate with alternating current input as well as 12-24 V direct current input provided by solar panels / batteries. Without photocell there is no risk of the pollution, bird-droppings etc. harming the sensor operation. In case of control module failure the luminaire goes to full brightness.

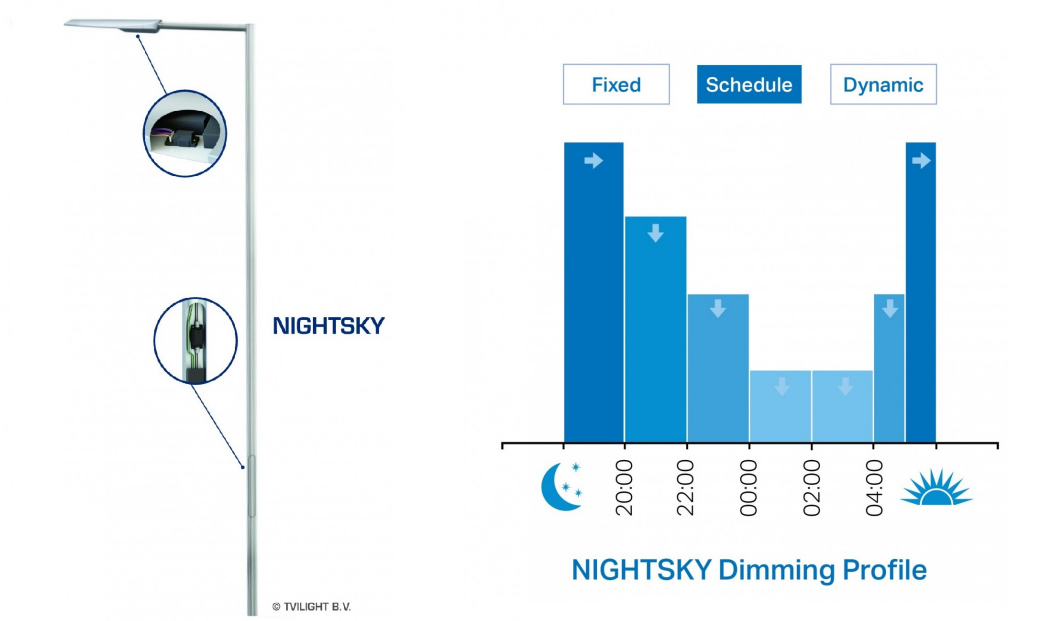

Figure 27 – Left: Installation of NightSky control module either inside the luminaire or inside the pole. Right: An example of a programmed multi-step dimming profile. [42]

Configuring happens by using Tvilight software with SmartFlash interface tool connected to a PC terminal . This allows user to define custom dimming and switching profiles, including options for different profiles for weekdays and weekends. Example of dimming schedule adjustment is presented in Figure 27. Also features such as local sunset/ sunrise times can be enabled or disabled. Once programmed, NightSky remembers the time and the local conditions for up to 20 years. Tvilight states that soon also the estimated energy saving forecast can be calculated with the SmartFlash software and the CLO feature is coming in the next versions too.

Compared to nightDim, NightSky is suited for operation also with continous 24-hour power supply, so there is no need for external timers or photocells apart from the NightSky module. The adjustment possibilities of the dimming schedule are more extensive too, as illustrated in Figure 27. The configuration must be done with PC and the proprietary tool and software though, no remote controlling is possible.

4.3 Comparison chart of indoor stand-alone lighting solutions

The most relevant specifications and functions of the indoor stand-alone lighting solutions are compared on the next page in the chart presented in Table 2. As the Digital Lumens DLA products and Tridonic ready2mains technology are not capable for pure stand-alone functionality, they are not included in the comparison chart. From the Schneider and Lutron products the wired stand-alone components and then Lutron wireless product family are chosen into comparison. Focus being in indoor and non-residential environments, it is assumed that the light source is either LED module or fluorescent lamp. The solutions are compared to the reference installation, a standard on/off manually switched luminaire. The comparison focuses mostly on the viewpoints of installers and users, so it is assumed that all the stand-alone components that are intended to be inside the luminaire are already installed there by the luminaire manufacturer. Positive advantages when compared to switching luminaires are marked with green font and the symbol • while the negative drawbacks are marked with red font and the symbol ◦. To give reference point in the other end of the scale too, complex non-stand-alone networked DALI solution is also included in the comparison. In that solution it is assumed that all the devices are connected with DALI cables and the system is programmable and controllable in a centralised way from any point. All the optional possibilities to extend or optimise the functionality are marked with grey font.

Table 2 – Comparison chart of indoor stand-alone lighting solutions.

	Switched luminaires (reference)	Helvar Active+ luminaires	Helvar iDim luminaires	Philips Actilume luminaires	Organic Response luminaires	freeDim / e-Sense Tune luminaires	Tridonic SMART sensor luminaires	Luminaires and Schneider / Lutron wired standalone components	Luminaires and Lutron wireless standalone components	Helvar Select the Weather stand-alone luminaires	DALI networked system (not stand-alone)
Supported light sources	LED Fluorescent	LED Fluorescent (with normal Active)	LED Fluorescent	LED Fluorescent	LED Fluorescent	LED ○ Not fluorescent	○ Not LED Fluorescent	LED Fluorescent	LED Fluorescent	LED ○ Not fluorescent	LED Fluorescent
Product investment: cost adding factors	Switching driver On/Off switches	○ Active+ driver ○ Sensor unit (PIR+CL) ● No switches required	○ iDim DALI driver ○ Sensor unit (PIR+CL+IR) ○ iDim Solo ○ Remote controller ● No switches required	○ DALI / 1-10V driver ○ Sensor unit (PIR+CL+IR) ○ Control module ○ Remote controller ● No switches required	○ DALI / 1-10V driver ○ Sensor node (PIR+CL+IR) ○ Controller ○ Infrared dongle ● No switches required	○ DALI Type 8 driver ○ Sensor unit (PIR+CL) ○ Master unit (Following units) ● No switches required	○ PCA EXCEL one4all DALI driver ○ Sensor unit (PIR+CL+IR) (Remote controller) ● No switches required	Switching driver (/Dimming driver) ○ Sensors/timers /dimmers	Switching driver (/Dimming driver) ○ Wireless transmitters (sensors/timers/ switches/dimmers) ○ Wireless Receivers	○ StW DALI driver ○ StW button panel ○ DALI power supply (PIR sensor)	○ DALI driver ○ DALI sensors ○ Programming interface ○ DALI power supply (Router) (DALI switches and panels)
Installation effort required	Mains cable to luminaire Cabling to the switches	Mains cable to luminaire ● No switches required	Mains cable to luminaire ● No switches required (DALI cables to linked luminaires) (PIR extension sensors)	Mains cable to luminaire ● No switches required (DALI cables to linked luminaires) (PIR extension sensors)	Mains cable to luminaire ● No switches required (Wired system node links)	Mains cable to luminaire ● No switches required	Mains cable to luminaire ● No switches required	Mains cable to luminaire ○ Mounting the sensors and/or switches ○ Cabling to the sensors and/or switches	Mains cable to luminaire ○ Mounting the sensors and/or switches ○ Syncing the devices	Mains cable to luminaire ○ Mounting the StW button panel ○ DALI control cabling to panel (Mounting the PIR)	Mains cable to luminaire ○ Mounting the sensors and switches ○ DALI control cabling between devices
Programming and configuration tasks before use	None	None ● Automatic PIR and daylight harvesting optimisation ● Automatic light level measurement and setting	○ Mode selection from the sensor wheel ○ Light level tuning with remote	○ Mode selection with the remote ○ Light level tuning with push button on the sensor or remote	○ Mode selection with the smartphone application ○ Light level tuning with smartphone application	○ Pairing the smartphone/s with the master unit with the smartphone application (Pairing the following units)	○ Light level tuning with push button on the sensor, DALI or remote	○ Setting the sensitivity, light level and time with buttons, potentiometers or remote controller	○ Setting the sensitivity, light level and time with buttons, potentiometers or remote controller	None	○ Commissioning ○ Programming ○ Trained DALI professional needed
Customisation possibilities	None	● Adjusting the parameters with smartphone application	● Adjusting the parameters with remote controller and PC software	● Adjusting the parameters with remote controller	● Adjusting the parameters with smartphone application	● Adjusting the parameters with smartphone application	(Adjusting the parameters with PC interface and DALI programming software)	● Adjusting the sensitivity and timers	● Adjusting the sensitivity and timers	(Customised scenes with PC interface and DALI Toolbox / Designer software)	● Full customisation of the whole network with PC interface and DALI programming software
Everyday use / control	On/off switch	● Fully automatic	● Fully automatic Possibility to use: (Switch&dim control) (Remote controllers)	● Fully automatic Possibility to use: (Switch&dim control) (Remote controllers)	● Fully automatic Possibility to use: (Wireless wall control panel) (Smartphone application)	● Fully automatic Possibility to use: (Smartphone application)	● Fully automatic Possibility to use: (Switch&dim control) (Remote controller)	● Automatic use with PIR/dusk/light sensors Possibility to use: Wall switches (Timers) (Dimmers)	● Automatic use with PIR/dusk/light sensors Possibility to use: Wall switches (Timers) (Dimmers)	● Push-button panel (Automatic use with PIR) Possibility to use: (Remote controllers with the panel)	● Fully automatic with sensors ● Possible centralised control Possibility to use: Switches (Dimmers) (Control panels)
Energy saving features	-	● Occupancy sensing ● Daylight harvesting ● Automatic constant lumen output ● Accuracy with sensor in each luminaire	● Occupancy sensing ● Daylight harvesting ● Constant lumen output ● Accuracy with sensor in each luminaire (not in the linked ones)	● Occupancy sensing ● Daylight harvesting ● Constant lumen output ● Accuracy with sensor in each luminaire (not in the linked ones)	● Occupancy sensing ● Daylight harvesting ● Constant lumen output ● Accuracy with sensor in each luminaire	● Occupancy sensing ● Smartphone sensing ● Daylight harvesting and constant lumen output in adapt mode	● Occupancy sensing ● Daylight harvesting ● Constant lumen output ● Accuracy with sensor in each luminaire	● Occupancy sensing ● Dusk switching (Daylight harvesting)	● Occupancy sensing ● Dusk switching (Daylight harvesting)	(Occupancy sensing with PIR)	● Occupancy sensing ● Daylight harvesting ● Constant lumen output
Lighting comfort features	-	● Dimming ● Constant light ● Smooth fade times	● Dimming ● Constant light ● Smooth fade times	● Dimming ● Constant light ● Smooth fade times	● Dimming gradually around the user ● Constant light ● Smooth fade times	● Tunable white ● Dimming ● Constant light ● Smooth fade times	● Dimming ● Constant light ● Smooth fade times	(Dimming) (Constant light)	(Dimming) (Constant light)	● Tunable white ● Automatic dynamic weather mode ● Dimming ● Smooth fade times	● Dimming ● Constant light ● Smooth fade times (Tunable white)
Actions needed after changes in room layout and purpose	Cabling changes	● Resetting Adjusting the parameters with smartphone application	● Mode selection Custom adjustment Cabling changes in linked luminaires	● Mode selection Custom adjustment Cabling changes in linked luminaires	● Mode selection Adjusting the parameters with smartphone application	● Pairing the master units to appropriate smartphone/s again And to following units	● DALI reprogramming (Needs PC interface and DALI programming software)	Cabling changes Adjusting sensitivity and the timers Reinstalling the sensors	● Resyncing the devices Adjusting sensitivity and the timers Reinstalling the sensors	Cabling changes Reinstalling the button panel Reinstalling the PIR	● DALI reprogramming Reinstalling the sensors
DALI Future scalability	-	-	● Compatible with all DALI products	● Compatible with all DALI products	● Compatible with all DALI products	● Compatible with all DALI products	● Compatible with all DALI products	-	-	● Compatible with all DALI products	● Compatible with all DALI products
Possibility to monitor data of each individual luminaire in centralised way	No	No	No	No	No	● Yes, with freeDim gateway	No	No	No	No	● Yes (burning hours, energy consumption, error messages etc.)
Connections and methods of integration to external BMS	No	No	● Single iDim luminaires (With DALI router)	● Single or parallel Actilume luminaires (With Loytec gateway)	● Whole system within infrared/link connection chain (With Ethernet gateway)	● Single or multiple freeDim systems (With freeDim gateway)	● Single SMART luminaires (With DALI router)	● Some individual sensors (they share data, but do not take commands from BMS)	● Single or multiple sensor and buttons (With CCO module, the data is sent there, but it does not take commands from BMS)	● Single StW systems (With DALI router)	● Whole network (With DALI router)

4.4 Comparison chart of outdoor stand-alone lighting solutions

The outdoor stand-alone lighting solutions are compared in the chart presented in the Table 3. In the light source compability comparison the support for LED and HID light sources is reviewed, because they are commonly used in outdoor environments. Since a some sort of system is needed to manage the lighting to switch on and off in the evening and in the morning, the solutions are compared to normal on/off switching luminaires connected to a timer or a dusk switch, which are common outdoor lighting controls. And as with the indoor lighting solutions too, it is assumed that all the stand-alone components that are intended to be inside the luminaire are already installed there by the luminaire manufacturer. Positive advantages when compared to switching luminaires are marked again with green font and the symbol • while the negative drawbacks are marked with red font and the symbol ◦. All the optional possibilities to extend or optimise the functionality are marked with grey font.

Table 3 – Comparison chart of outdoor stand-alone lighting solutions.

	Outdoor switching luminaires (reference)	Helvar nightDim luminaires	BEGA connection box luminaires	Schreder Owlet luminaires (stand-alone mode with no wireless network)	Philips Dynadimmer luminaires	Philips Xitanium / Osram 2/3/4DIM programmable driver luminaires (Dynadimmer / AstroDim)	Philips Xitanium / Osram 2/3/4DIM programmable driver luminaires (LineSwitch / StepDim)	Tvilight NightSky luminaires
Supported light sources	LED HID	LED ○ Not HID	LED HID	LED HID	LED HID	LED HID (Osram)	LED HID (Osram)	LED HID
Product investment: cost adding factors	Switching driver Timer or dusk switch (only one needed for group control)	○ NightDim DALI driver Timer or dusk switch	○ 1-10V driver ○ Control module Timer or dusk switch	○ DALI / 1-10V driver ○ Photocell and/or control module (with ZigBee components) (Motion sensor)	○ 1-10V driver ○ Control module (Official remote programmer) Timer or dusk switch	○ Xitanium / 2/3/4DIM driver ○ Programmer interface Timer or dusk switch	○ Xitanium / 2/3/4DIM driver ○ Programmer interface Timer or dusk switch ○ Control line timer/switch	○ DALI / 1-10V driver ○ Control module (with astronomical clock) ○ SmartFlash programmer interface
Installation effort required	Mains cable Cabling to the timer/switch	Mains cable Cabling to the timer/switch (Manual on/off switching possibility)	Mains cable Cabling to the timer/switch	Mains cable ● No additional timer or dusk switch required	Mains cable Cabling to the timer/switch	Mains cable Cabling to the timer/switch	Mains cable ○ Control line cable Cabling to the timer/switch	Mains cable ● No additional timer or dusk switch required
Programming and configuration tasks before use or during use	Setting the timer / dusk sensor level	Setting the timer / dusk sensor level ○ Setting the nighttime dimming schedule remotely with mains pulses	Setting the timer / dusk sensor level ○ Setting the nighttime dimming period with potentiometer in each luminaire	○ Commissioning ○ Programming ○ Schréder field application engineer needed	Setting the timer / dusk sensor level ○ Setting the dimming schedule with PC or with remote programmer	Setting the timer / dusk sensor level ○ Setting the parameters with PC and programmer interface	Setting the timer / dusk sensor level ○ Setting the parameters with PC and programmer interface	○ Programming with PC and SmartFlash tool
Customisation possibilities	Adjusting the timer / dusk sensor level	Adjusting the timer / dusk sensor level Adjustable: ● Static level ● Dimming length	Adjusting the timer / dusk sensor level Adjustable: ● Dimming length	Adjusting the astronomical clock/ light sensor level (Adjusting motion sensor sensitivity) Adjustable: ● Dimming length ● Dimming level ● Multiple periods	Adjusting the timer / dusk sensor level Adjustable: ● Dimming length ● Dimming level ● Multiple periods	Adjusting the timer / dusk sensor level Adjustable: ● Dimming length ● Dimming level ● Multiple periods	Adjusting the timer / dusk sensor level Adjustable: ● Dimming length with control line timer ● Dimming level	Adjusting the astronomical clock Adjustable: ● Dimming length ● Dimming level ● Multiple periods
Everyday use / control possibilities	Automatic switching	Automatic switching ● Automatic energy savings during the night ● Remote configuring with mains pulses	Automatic switching ● Automatic energy savings during the night	Automatic switching ● Automatic energy savings during the night	Automatic switching ● Automatic energy savings during the night	Automatic switching ● Automatic energy savings during the night ● Override possibility with control line	Automatic switching ● Automatic energy savings during the night ● Override possibility with control line	Automatic switching ● Automatic energy savings during the night
Energy saving features during the night	-	● Adjustable dimming schedule ● Constant lumen output	● Adjustable dimming schedule	● Adjustable dimming schedule (Motion detection) ● Constant lumen output	● Adjustable dimming schedule	● Adjustable dimming schedule ● Constant lumen output (LED drivers)	● Adjustable dimming schedule ● Constant lumen output (LED drivers)	● Adjustable dimming schedule ● Constant lumen output
Lighting comfort features	-	● Dimming ● Smooth transition fade times	● Dimming	● Dimming	● Dimming ● Smooth transition fade times	● Dimming ● Smooth startup ● Smooth transition fade times	● Dimming ● Smooth startup ● Smooth transition fade times	● Dimming
DALI Future scalability	None	● Compatible with all DALI products	-	● Compatible with all DALI products	-	● Compatible with all DALI products	● Compatible with all DALI products	● Compatible with all DALI products

4.5 Summary and conclusions

Examining the competitors in the stand-alone lighting market, it is clear that there is notable diversity in the solutions. Most are luminaire-based solutions, but there are also external stand-alone sensors to achieve value-adding functionality. DALI is the most common protocol when communicating with dimmable drivers, but products with 0-10V and 1-10V interface are also offered. Communications between devices in different solutions are realised via cables, radio frequency signals or infrared signals.

Indoor stand-alone lighting solutions

When the indoor lighting solutions are examined, the Active+, freeDim and Select the Weather solutions support only LED drivers, while the other solutions are compatible with LED or fluorescent light sources (SMART sensors only with fluorescent). The sales of traditional light sources is decreasing all the time however, and LED market share is forecasted to be over 70% of total sales in 2019. [2]

Concerning product investment and costs, most of the extra costs compared to the switching luminaires are accumulated from the dimmable drivers, sensors and different control modules that raise the system total price. Also wireless transmitters and receivers, transforming the signal to infrared, ZigBee, Bluetooth etc. increase costs. In this sense, Active+ and SMART sensors have the advantage of having no wireless components and no need for separate power supply or control module for the sensor unit since all that is built in the driver or ballast. Even the standalone sensor units have integrated separate power supplies in addition to the luminaire driver and that increases the costs. No remote controller investments are needed for Active+ as the smartphone acts as the adjustment tool as it is.

All the stand-alone solutions with sensors integrated into luminaires are the most simple to install, as only the mains cable to the luminaire is needed, although iDim Basic and Actilume give the opportunity to link slave luminaires with cables too. Stand-alone external sensors need more installation effort, as does also the button panel of Select the Weather. On the other hand it still operates without the panel, but the dynamic scene is then always on.

Active+ and Select the Weather are the solutions that are designed to operate without any initialising in any environment. Active+ is the only one that optimises its behaviour automatically by self-learning. All the other ones need user or installer efforts to achieve the optimal operation in the installation environment. Configuring happens by buttons, potentiometers, remote controllers or smartphones. In the terms of product costs and installing as well as programming, the reference of DALI networked system is the most challenging of the solutions. This is because of having the combined needs for power supply, programming interface, mounting and cabling the external sensors and eventually commissioning and programming the system by trained professional.

Although many offering basic plug&play operation capabilities, all of the products offer some kind on chances to customise the operation. Stand-alone sensors have only adjustable sensitivity and timers, while the other ones offer more sophisticated functions, such as minimum and maximum light levels or scene setting. The smartphone configuration of Active+, Organic Response and freeDim means that the configuring device is probably always there with the user. While designed to be really plug&play, Select the Weather does not offer any convenient way to alter its operation, apart from the possibility to program it with DALI tools. Same applies for the SMART sensors.

The advantage of many other luminaire-based solutions over Active+ is different scenes to choose from. These can be activated from remote controllers, wall panels or smartphones. The ease of use in normal situations is optimal because the systems operate fully automatically with sensors without the need for user input. When a change in lighting is desired, most solutions offer various ways to do that. Here DALI networked system has the significant advantage of controlling the whole connected lighting network in a centralised way from one single point.

All the solutions offer various features to save energy, and Active+, iDim Basic, Actilume, Organic Response and SMART luminaires achieve the widest functionality with occupancy sensing, daylight harvesting, constant lumen output and increased accuracy of the operation because of sensors in every luminaire. However, Active+ is the only one of these which is capable of automatic constant lumen output feature, in other models the light sensor setpoint must be manually calibrated to suit the installation environment and only then the constant lumen output works optimally. In Organic Response the daylight harvesting mode must be also first activated. The gradual networked dimming pattern of Organic Response solution increases the visual comfort of users in larger rooms such as open-plan offices, but at the same time increases also the energy consumption by some amount when compared to individually behaving sensor-equipped luminaires when entering a dark room.

Otherwise when lighting comfort is concerned, luminaire-based solutions offer more features than the external Schneider and Lutron stand-alone sensors. Distinct advantages are offered by freeDim and Select the Weather in the form of tunable white technology. Although the research has not conclusively proven the long-term effects to humans, there is a clear potential of human centric lighting for increasing the well-being of persons spending their time inside [23].

When changing the layout or the purpose of the space and building, on/off switching luminaires must potentially be cabled in a new way to appropriate switches. Most of the stand-alone solutions have advantages over that with better adaptability, only wired stand-alone sensors and Select the Weather need re-cabling in the drastic layout changes. Active+, iDim Basic, Actilume, Organic Response, freeDim and wireless stand-alone sensors do not require necessarily physical changes, as the reconfiguring can be made on the software level, as with the DALI system too. Exception may be the linked slave luminaires of iDim Basic and Actilume or external sensors that need relocating. To achieve the tailored adjustments for the new environment, the

other individually operating luminaires need manual mode selection and connected devices resyncing, but with Active+ the reset of the system gets the driver and sensor to learn the new settings automatically. This takes 60 - 100 hours though, so when desiring immediate effect, Active+ can be configured manually too with the smartphone application.

When taking possible future scalability into account, the products with DALI drivers can be always integrated into wired DALI network, although losing the stand-alone characteristics then. When DALI compatible, the stand-alone sensors can be also connected to DALI luminaires, thus leaving Active+ the only solution not supporting DALI standard. Helvar is however going to launch a driver that includes both Active+ functionality as well as full DALI support, having also switch&dim inputs for manual control. The main target of Active+ is to be an affordable stand-alone solution however, so the non-DALI version is examined in this comparison.

Because the DALI networked system has all of the devices connected to each other, one significant benefit is the possibility to monitor data from each luminaire in a centralised way from one point of the network. This requires of course appropriate hardware and software to read the data. From the stand-alone solutions, freeDim offers the chance to deliver all this DALI data from wirelessly connected multiple systems and units through one freeDim gateway.

As comes into attention in chapter 6, integration of lighting into building management systems is anticipated to grow more common in the near future. In theory, single iDim Basic, Actilume and SMART luminaires or Select the Weather systems can be connected to DALI router and thus to BMS, but it is not cost-effective. They must be cabled together first, losing the stand-alone operation. When wanting occupancy information to BMS, stand-alone sensors can be a valid choice, giving signals to both lighting devices and building management system. As earlier mentioned, the freeDim gateway can share data with multiple freeDim systems and DALI router in one point, and Organic Response ethernet gateway manages the same. With Organic Response, all the devices in the infrared chain are included in the communications. These systems can both share e.g. occupancy information to the BMS as well as take commands to set certain lighting scenarios. Networked DALI system is the most robust choice with BMS integration, having wired connections to every device in the network communicating with the router.

All in all, when comparing Active+ to the other competitors, it can be seen that the benefits of Active+ are in the cost-effective component structure, simple installation, self-learning initialisation process and various energy-saving functions. Lighting comfort functionality is among the best, and adaptation to changes is simple with the resetting possibility and the new smartphone application. Drawbacks are the limited user control options and connectivity, as well as restrictions in upgrading or extending the features. Active+ being stand-alone solution however, there are more suitable alternatives on the market to answer those challenges.

Select the Weather is not as simple to install and not featuring as many energy-saving functions as Active+, but it has the benefit of tunable white light. There are not many solutions on the commercial lighting market offering chance to implement human centric lighting as a stand-alone solution. Since based on DALI standard the future scalability is good, but Select the Weather still offers plug&play stand-alone operation without the need of any programming or commissioning, which is an important benefit and unique value driver.

Outdoor stand-alone lighting solutions

In the case of outdoor lighting solutions, nightDim is the only one to support only LED light sources. When the lighting control is concerned, LEDs are more flexible to control though, as the most HID light sources have restrictions in the dimming range [43]. When examining cost adding factors, nightDim is the only solution in the comparison that does not need additional control/sensor module or programming interface. There are also no built-in wireless components which would increase the initial costs. All the solutions except Owlet and NightSky need the external timer or dusk switch to manage the switching of luminaires before and after the dark time. Single timer or switch can control a group of luminaires however, and even though enabling more precise control, photocell or astronomical real-time clock in every luminaire in large installations results in probably higher initial costs.

Installation effort required is quite similar in all of the solutions. The Owlet and NightSky have the advantage of not requiring the external timer or switch, and Lineswitch/StepDim installers need to install the additional control line cable to the drivers. NightDim needs the possibility to switch the mains on and off manually, but that can be done with the circuit breaker if no switch exists, as the adjustment is not likely to be required daily, weekly or even monthly.

When configuring the products before and during the use, all solutions except nightDim are configured locally and one luminaire at a time. During use, presumably the light poles or luminaires must also be opened to get access to the devices, which requires considerable effort. Philips, Osram and Tvilight solutions need even PC or remote programmer and Schréder advertises their own field application engineers to handle the programming. NightDim has the advantage of remote configuring with the mains pulses to a larger group of luminaires simultaneously. One challenge is the situation when smaller groups or individual luminaires should be configured, then more manual switches are needed.

In the customisation possibilities nightDim cannot match the options of multiple periods, levels and lengths of nighttime dimming that other products offer. All the solutions enable automatic energy savings during the night though, and in the terms of control nightDim has the mentioned advantage of remote configuration with mains pulses. For emergency or temporary situations, Philips and Osram drivers in the comparison offer the chance to override dimming profile with a signal from the control line, if that is installed.

In addition to the adjustable dimming schedule for the night, the programmed CLO function offered by nightDim, Owlet, Philips/Osram drivers and NightSky improve the energy efficiency further. One advantage of Owlet solution would be using the optional motion detector connection, so the light level would be dynamically adjusted according to the moving persons outside. Extra motion sensors in every luminaire increase costs though and add up to initial investment.

The dimming capability of all the compared solutions reduce the light output and thus glare also, improving lighting comfort during the night. On the other hand, too dark environment is not optimal either for visual comfort. NightDim and Philips/Osram products improve comfort further with smooth transition fade times between changing dimming levels. Philips drivers have even the option to adjust startup fade time to full brightness after switching on the luminaires. Apart from BEGA connection boxes and Dynadimmer control module all the solutions function with DALI capable drivers, which leaves the possibility for the user to integrate them later in a DALI network.

When compared to other similar products on the market, nightDim has its benefits in the simplicity of installation, configuration and the technical structure of the system, reducing the initial costs. When not offering as much adjustability as many other products, nightDim has still the same principle of scheduled dimming with a control method that anyone can use. No PC, additional tools or trained professionals are required.

5 Measurable benefits

5.1 Energy savings

In this chapter five cases of Active installations and their energy consumptions are examined. The data for the first four cases was given by Helvar, all the setups there are real-life cases. The installations were done with original Active fluorescent ballasts, with iDim Solo power supply and the old sensor. Data was collected from the ballasts themselves, which had registered and stored the data during the operation. The data includes the total burning hours of the luminaires, total energy consumed, average power and power percentage they used during the time when the light was on, how many times the lamps were switched on, how many times the whole luminaire was powered up, what was the calibrated light level, did they enter the "alone" or "external light" modes, how long was the learning time, after how long time the luminaire started to fade the light down after absence and how long was the delay before switching it completely off. Learning time is not taken into account in other collected data, except in the Helvar R&D office case.

The reference luminaires, which the Active luminaires are compared to in the first four cases when calculating energy savings, are theoretical. They are assumed to be identical manually on/off switched luminaires with equivalent electronic ballasts and operating at full power. The burning hours are calculated as the same amount as the Active luminaire with the most burning hours. In reality, they would have even more burning hours, if the lights were continuously on from morning to the evening. The amount would then drop in case of switching the lights off manually during the workdays, but the Active luminaire with the most hours was selected as a most realistic assumption for reference level burning hours. There is also some level of measurement error in the data that the drivers have collected because of simplified algorithms for calculating the power consumption, but Helvar staff approximated the error to be in the range of $\pm(5-10)\%$ at the most.

The fifth case examined in this chapter is based on a final project study made in the premises of Aalto University, where modern LED luminaires with and without Active solutions were installed and evaluated.

5.1.1 Case open-plan office room

Helvar Active solution was installed in six luminaires in a company open-plan office room, in southern Finland. The company is left anonymous in this thesis. Install date was 21.1.2015. The luminaires were equipped with two 49W fluorescent tubes and 2x49W Active ballasts. Full power of one such luminaire at 100%, including the driving electronics, was measured to be 107,0W. The data gathered from the drivers is presented in Table 4.

Table 4 – Collected data from the luminaires in the open-plan office room.

Luminaire name	Burning hours [h]	Energy [kWh]	When ON Power (average) [W]	When ON Power (average) %	Lamp start amount	Power-up amount	CL level 0-255	Mode "Alone"	Mode 'External light'	Learning time [h]	PIR delay [minutes]	PIR OFF [minutes]
Luminaire 1	1288	120,9	93,87	87,73	1098	14	200	yes	no	72	5	10
Luminaire 2	1931	159,8	82,76	77,34	297	14	69	no	no	65	10	85
Luminaire 3	2282	186,5	81,73	76,38	303	10	60	no	no	67	10	85
Luminaire 4	1640	130,5	79,57	74,37	392	10	61	no	no	71	10	85
Luminaire 5	3647	304,7	83,55	78,08	393	139	81	no	yes	73	10	85
Luminaire 6	2687	187,7	69,85	65,28	427	14	73	no	yes	66	10	85
Total actual	13475	1090,1										
Reference	21882	2341,4										
Total savings		**53 %**										

The six luminaires were stationed in the room as shown in the Figure 28. One of them was in the middle of the room near a large window to the corridor, which was always lit. Others were positioned above different workstations, one isolating partition being also in the room. On the longer wall opposite the corridor, there were two small windows near the ceiling.

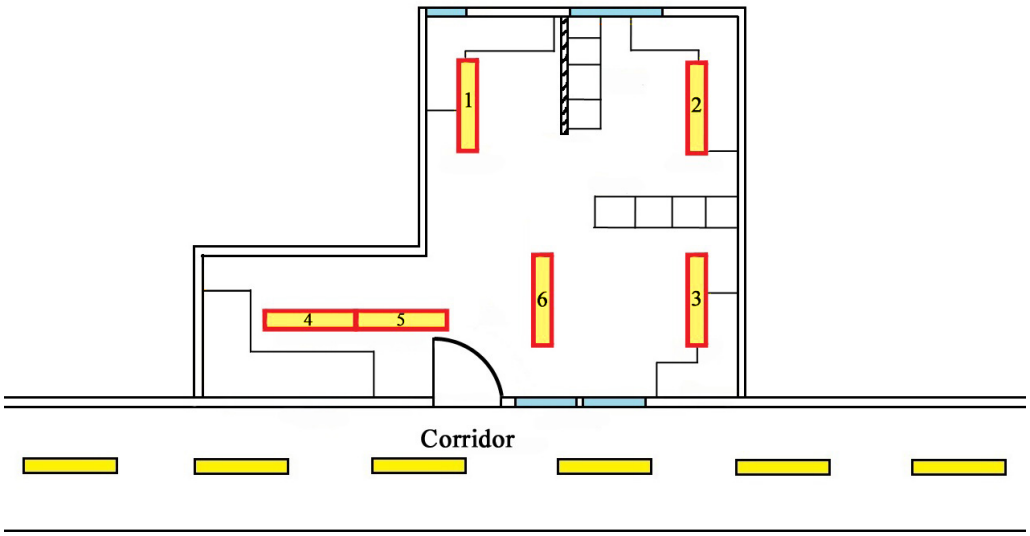

Figure 28 – Layout of the open-plan office room in the Finnish company.

The luminaire 1 was isolated with walls and a partition and it was the only one to go to “alone” mode. Apparently the distance to other luminaires was long enough, as e.g. the luminaire 2 in the other corner did recognise others. In case of absence, the luminaire 1 switched the light off in relatively short time compared to others. Thus the average power was higher compared to the other luminaires. The amount of burning hours is also lower and lamp start amount substantially higher. The CL constant light level of 200 seems unproportionally high, there might have been some malfunction with the sensor. The luminaires 5 and 6 saw light from the corridor and were set to the “external light” mode, but the luminaire 3 did not. There is not any noticeable difference in the average power though. The windows on the opposite wall were really small and facing north, so there was not enough daylight to set the luminaires 1 and 2 to the "external light" mode. Total energy savings in the installation reached **53%** as illustrated in Figure 29.

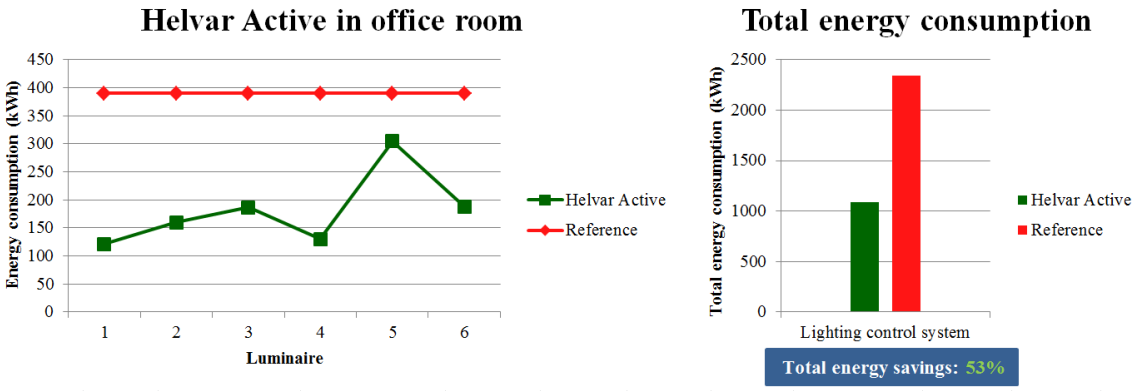

Figure 29 – Collected energy consumption data from the luminaires and the calculated energy savings in the open-plan office room.

5.1.2 Case Russian university

12 Helvar Active luminaires were installed in a university in Russia, left also anonymous. The install date was 21.3.2014. The luminaires were equipped with four 14W fluorescent tubes and 4x14W Active drivers, full power at 100% was measured to be 63,5W. The data gathered from the drivers is presented in Table 5.

Table 5 – Collected data from the luminaires in the Russian university.

			When ON	When ON								
Luminaire name	**Burning time [h]**	**Energy [kWh]**	**Power (average) [W]**	**Power (average) %**	**Lamp start amount**	**Power-up amount**	**CL level 0-255**	**Mode "Alone"**	**Mode "External light"**	**Learning time [h]**	**PIR delay [minutes]**	**PIR OFF [minutes]**
Luminaire 1	309	13,8	44,66	70 %	273	266	78	no	no	69	10	85
Luminaire 2	308	13,8	44,81	71 %	265	263	56	no	no	69	10	85
Luminaire 3	297	14,2	47,81	75 %	278	263	67	no	no	72	10	85
Luminaire 4	307	13,4	43,65	69 %	267	263	65	no	no	70	10	85
Luminaire 5	309	13,7	44,34	70 %	278	271	54	no	no	72	10	85
Luminaire 6	303	12,6	41,58	65 %	283	268	62	no	no	71	10	85
Luminaire 7	314	14,8	47,13	74 %	269	266	52	no	no	69	10	85
Luminaire 8	311	13,6	43,73	69 %	273	266	49	no	no	70	10	85
Luminaire 9	305	14,6	47,87	75 %	278	266	58	no	no	71	10	85
Luminaire 10	285	11,5	40,35	64 %	302	264	49	no	yes	77	10	85
Luminaire 11	297	9,7	32,66	51 %	280	264	33	no	yes	72	10	85
Luminaire 12	282	12,4	43,97	69 %	286	264	45	no	yes	74	10	85
Total actual	3627	158,1										
Reference	3780	240,0										
Total savings		**34 %**										

The luminaires were stationed in the lecture room as shown in Figure 30. There were windows on the one wall of the room, and the luminaires were lined up in four rows, three luminaires per each. The three first rows were above the desks and seats. The three luminaires in the fourth row were near the windows and enabled the daylight harvesting mode, the others did not recognise enough external light.

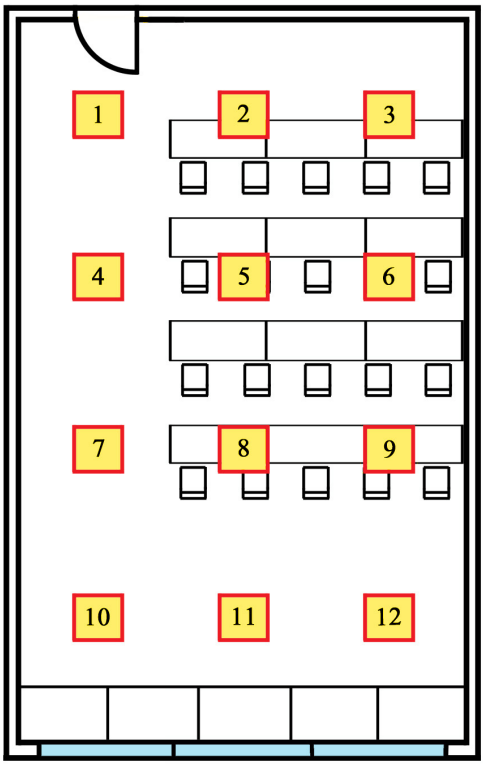

Figure 30 – Layout of the lecture room in the Russian university.

All the luminaires registered each other as they should. Luminaire 11, being in the middle of the windows, got the most advantage from the daylight. That can be seen as the lowest average power of all the luminaires. Lamp start amounts are quite close to the power-up amounts, so there has not been considerably many switch-offs by PIR sensor functionality. The total energy savings reached **34%** as illustrated in Figure 31. While being lower than in the first case study, it correlates to the fact that in the lecture room there is presence quite evenly throughout the day.

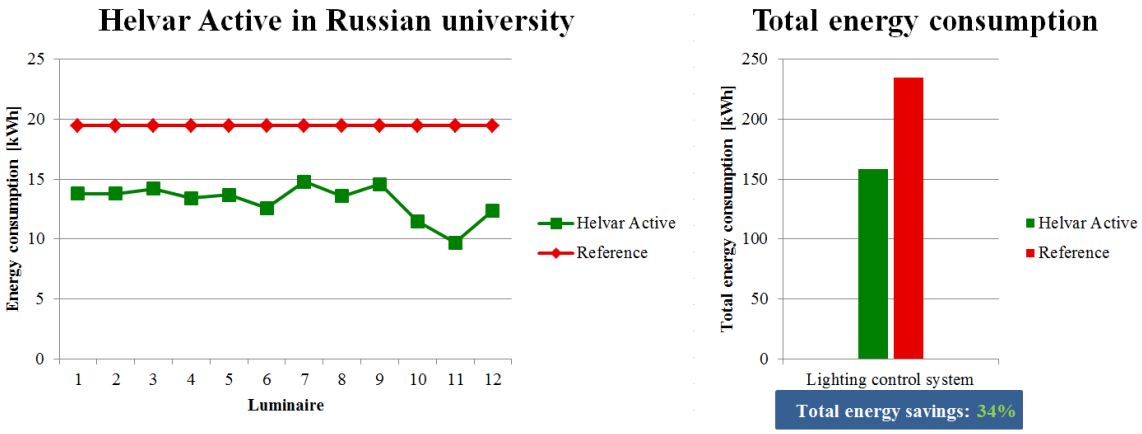

Figure 31 – Collected energy consumption data from the luminaires and the calculated energy savings in the Russian university.

5.1.3 Case Helvar R&D office

11 Helvar Active luminaires were installed in Helvar R&D office room in Karkkila, Finland. Date of the installation was 27.5.2013 and the data was collected 27.5.2015, operating time being two years. Each luminaire was fitted with two 28W fluorescent tubes and 2x14-35W Active ballasts, full power measured to be 61,6W. The data gathered from the drivers is presented in Table 6.

Table 6 – Collected data from the luminaires in the Helvar R&D office.

			When ON	When ON							
Luminaire name	**Burning time [h]**	**Energy [kWh]**	**Power (average) [W]**	**Power (average) %**	**Lamp start amount**	**Power-up amount**	**CL level 0-255**	**Mode "Alone"**	**Mode "External light"**	**PIR delay [min]**	**PIR OFF [min]**
Luminaire 1	Luminaire changed										
Luminaire 2	4157	159,8	38,44	62,4	898	6	115	no	yes	10	85
Luminaire 3	2667	113	42,37	68,78	835	6	81	no	yes	10	85
Luminaire 4	3022	118,6	39,25	63,71	886	6	70	no	yes	10	85
Luminaire 5	3168	134,1	42,33	68,72	780	6	121	no	yes	10	85
Luminaire 6	Luminaire removed										
Luminaire 7	5480	234,3	42,76	69,41	738	6	56	no	yes	10	85
Luminaire 8	4980	199,8	40,12	65,13	866	6	53	no	yes	10	85
Luminaire 9	Minisensor detached										
Luminaire 10	4671	144,8	31	50,32	955	11	55	no	yes	10	85
Luminaire 11	3697	133,9	36,22	58,8	1027	6	72	no	yes	10	85
Total actual	31842	1238,3									
Reference	43840	2700,54									
Total savings	54 %										

The luminaires are positioned in the room as shown in the Figure 32. Seven of them are above the workdesks and four in the corridor. There are windows on one wall all along the way, facing northeast.

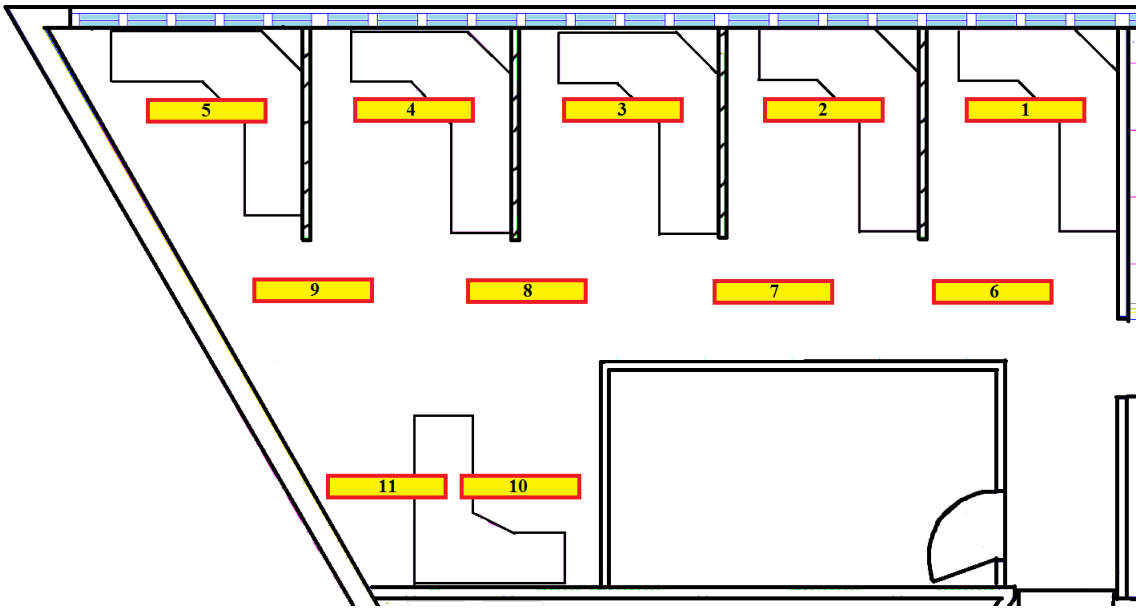

Figure 32 – Layout of the Helvar R&D office room.

The sensors were attached to the louvres in the luminaires, as shown in the photograph taken from one of the luminaires in Figure 33. The sensor of luminaire 9 was unfortunately detached at some point, so no reliable data could be salvaged. Luminaire 6 had been removed earlier and luminaire 1 was changed to other version. These three luminaires were thus not taken into account in the calculations. Because of the driver software version, in this case the learning period is also included in the data presented, such as total burning time and energy consumed.

Figure 33 – An Active fluorescent luminaire with the sensor attached to the louvre.

Most of the movement happened in the corridor, so the luminaires 7 and 8 have the most burning hours. The luminaires were installed in summertime, and it was so sunny outside that all luminaires have registered external light. None of them has entered the "alone" state. Total energy savings reached **54%** as illustrated in Figure 34.

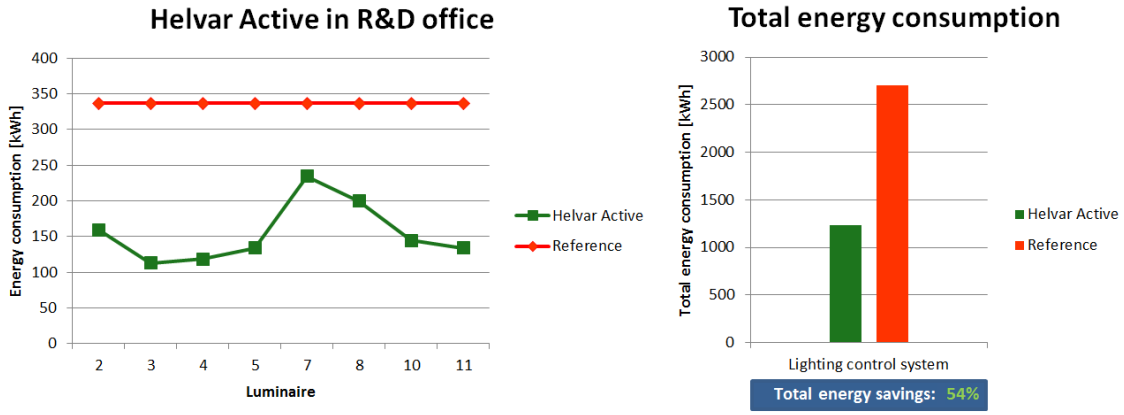

Figure 34 – Collected energy consumption data from the luminaires and the calculated energy savings in the Helvar R & D office.

5.1.4 Case Helvar type testing laboratory

Eight Helvar Active luminaires were installed in Helvar type testing laboratory in Karkkila, Finland. Date of the installation was 11.7.2013 and the data was collected 27.5.2015, operating time being almost two years. The luminaires were equipped with four 14W fluorescent tubes and 4x14W Active drivers, full power at 100% was 63,5W. The data gathered from the drivers is presented in Table 7.

Table 7 – Collected data from the luminaires in the Helvar type testing laboratory.

			When ON	When ON								
Luminaire name	**Burning hours [h]**	**Energy [kWh]**	**Power (average) [W]**	**Power (average) %**	**Lamp start amount**	**Power-up amount**	**CL level 0-255**	**Mode "Alone"**	**Mode "External light"**	**Learning time [h]**	**PIR delay [minutes]**	**PIR OFF [minutes]**
Luminaire 1	1693	84,9	50,148	78,97	6357	8	37	yes	no	95	5	10
Luminaire 2	1703	82,4	48,39	76,2	6645	12	35	yes	no	95	5	10
Luminaire 3	3617	173,6	48	75,58	6258	14	58	yes	yes	83	5	10
Luminaire 4	5741	276,6	48,18	75,87	718	9	37	no	no	79	10	85
Luminaire 5	5003	225,6	45,09	71,01	775	9	49	no	no	92	10	85
Luminaire 6	5277	175,8	33,31	52,46	787	8	52	no	yes	94	10	85
Luminaire 7	6077	222,2	36,56	57,58	1467	5	65	no	yes	97	10	85
Luminaire 8	4584	133	29,01	45,69	917	5	61	no	yes	96	10	85
Total actual	33695	1374,1										
Reference	48616	3087,116										
Total savings	**55 %**											

There are several rows of luminaires in the type testing building, and the middle row was equipped with Active ballasts and sensors. The luminaires are stationed in the building as shown in Figure 35. Three are in the office room, one in the lobby and the rest in the laboratory side.

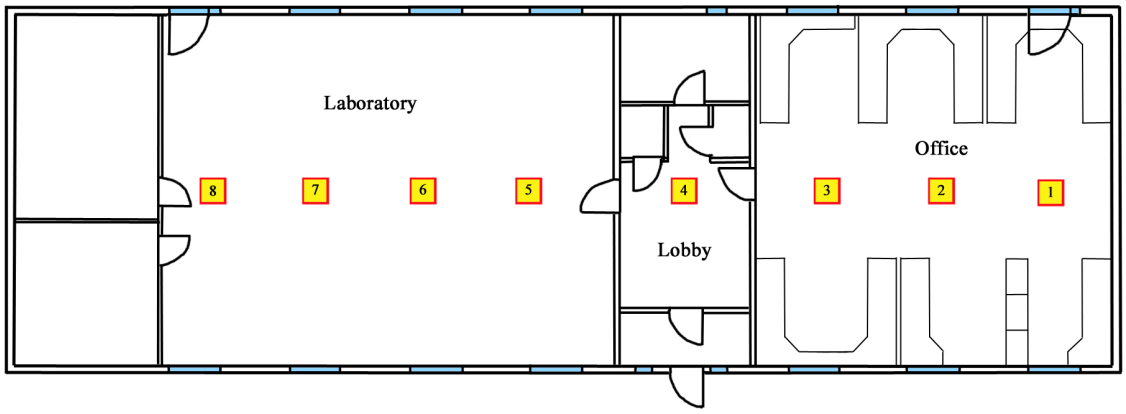

Figure 35 – Layout of the Helvar type testing laboratory building.

The laboratory staff spend a lot of time in the laboratory and less in the office, so there is a lot of absence in the actual office. The three luminaires also entered "alone" mode, presumably because of long enough distances between them or then the interference caused by all the other normal luminaires, being constantly switched on. This can be seen as substantially less burning hours and more times when switching the lamp on in luminaires 1-3 compared to the others. All the luminaires have relatively long learning periods, so they have been supposedly switching on and off quite constantly. Total energy savings reached **55%** as illustrated in Figure 36.

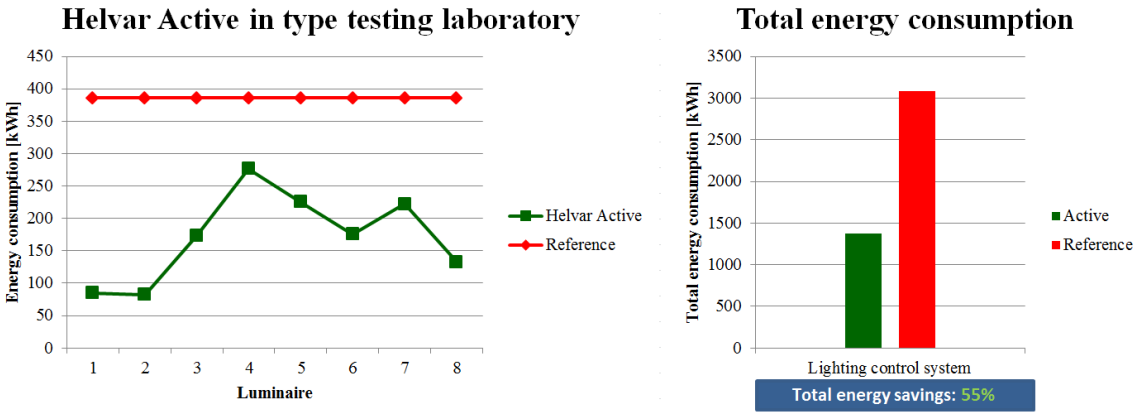

Figure 36 – Collected energy consumption data from the luminaires and the calculated energy savings in the Helvar type testing laboratory.

5.1.5 Case Aalto University offices

Gavioli [44] studied six office rooms in the building of Electrical Engineering in Aalto University, in Espoo, Finland, between September 2014 and March 2015. The layout of the rooms is presented in Figure 37, although the orientation of the tables there varied between the rooms.

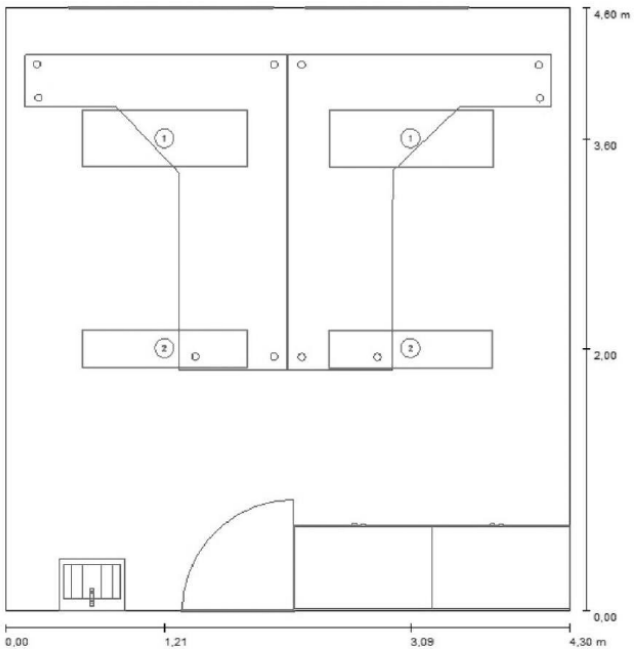

Figure 37 – Layout of the office rooms showing the positions of the four luminaires. [44]

In her case study, the six selected rooms had four luminaires each in the ceiling, equipped with an old Helvar L40G magnetic ballast and one 36W fluorescent tube per luminaire. The consumed power of the old luminaires was measured with a

digital power meter, resulting in 49W per luminaire. Two of the rooms were left as they were, and in four of them Alppilux LED luminaires were retrofitted. From those four rooms two were equipped with manually controlled 40W luminaires and the other two with Helvar Active luminaires with the nominal power of 35W.

The energy consumption of two LED luminaire equipped rooms was measured with digital power meters and compared to the consumption of one reference room with fluorescent lighting. The measurement was carried on for 13 weeks from December to March. The power consumption of the reference room was not measured, but it was calculated with the assumption that the lighting is switched on eight hours per workday. The results are presented in Table 8 and illustrated in Figure 38.

Table 8 – Measured and calculated total accumulated energy consumptions of luminaires in three office rooms in Aalto University. (Modified from [44])

	Accumulated energy consumption [kWh]													
Week	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Reference room (Fluorescent)	0	7,84	15,68	23,52	24,02	24,52	32,36	40,2	48,04	55,88	63,72	71,56	79,4	87,24
Test room 1 (LED luminaires)	0	4,8	10	14,8	15	15,4	20	26,4	32,6	39	46	52,8	58,6	64,6
Test room 2 (Active luminaires)	0	1,7	7,1	11,2	11,8	12,9	15,3	19,1	21,7	26,3	30,3	34,2	39	42,7

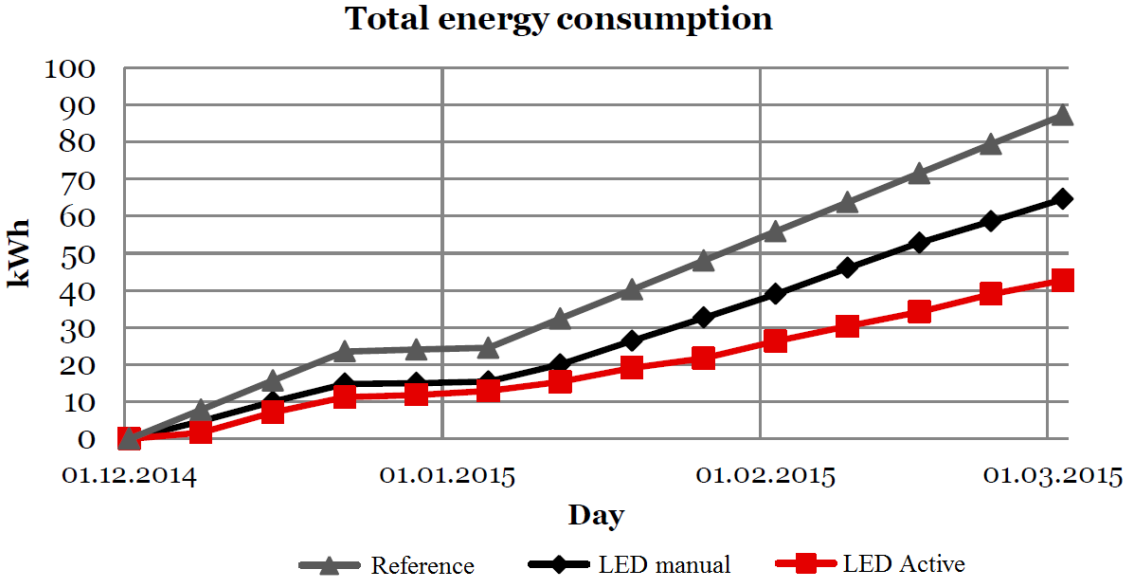

Figure 38 – Measured and calculated total accumulated energy consumptions of luminaires in three office rooms in Aalto University. (Modified from [44])

As it can be seen, the difference between the power of 87,24 kWh consumed by fluorescent lighting and the power of 64,6 kWh consumed by the manually controlled LED lighting results in a decrease of approximately 26% in power consumption. The Active LED luminaires on the other hand consume approximately **34% less** power

than the manually controlled LED ones in this study. The illuminance level and uniformity was improved in both cases of LED luminaire retrofittings compared to the old installations, resulting in very similar illuminance values.

While showing clear evidence of energy saving potential, the energy consumptions of switching and Active luminaires cannot be compared directly, because the nominal power of the Active luminaire was lower. Therefore Gavioli has studied the energy consumption also in terms of equivalent hours of maximum power by calculating the ratio between the metered kWh and the installed power. The calculated hours are presented in Figure 39.

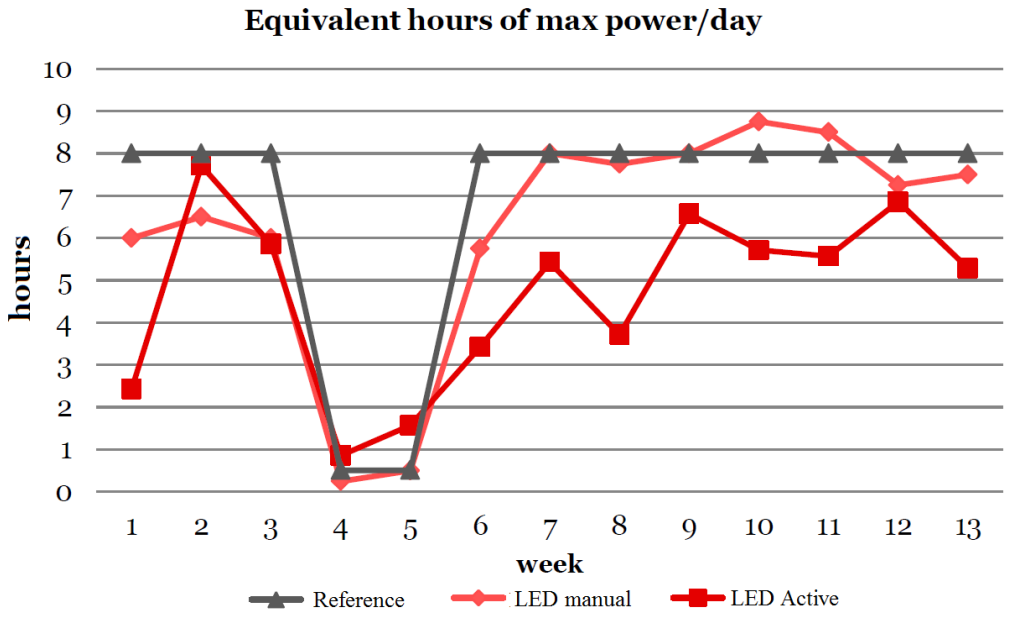

Figure 39 – Averaged equivalent usage hours of maximum power per day of the luminaires in three office rooms in Aalto University. (Modified from [44])

In her study, Gavioli made calculations based on the average luminaire daily usage hours presented in Figure 39 between week 7 and week 13 (when usage pattern stabilised after Christmas holidays) resulting in that in the room with manually switched LED lighting the luminaires are switched on 7 hours and 57 minutes per working day while in room with Active luminaires they are switched on 5 hours and 35 minutes. This suggests that a lighting system of a certain wattage equipped with Active functionality consumes on the average **30% less** power than the same system switched manually on and off.

These measurements were made in winter months however, so the daylight harvesting could not be taken much advantage of. According to Gavioli, when simulating the daylight with Dialux for the whole year, the Active LED luminaires benefitting from the daylight dimming were calculated to achieve 48% lower annual power consumptions than the manually controlled LED luminaires in the three rooms. It can be thus assumed, that if measured thoughout the whole year the Active solution would have achieved energy savings even greater than 30%.

5.2 Ease of use

Ease of use is an essential characteristic of any system that the end users have to interact with in the daily life. It is regarded as important part of lighting control system according to the studies [16, 17] and interviews (see chapter 6). There is no commonly agreed and discrete meter to measure the ease of use however, but some studies have researched the topic.

According to Davis [45] the perceived ease of use is the degree to which a person believes that using a particular system would be free of effort. The performance benefits of usage should not be outweighed by the effort of using the application, and a system that is easy to use is likely to be accepted by users, he states. Davis used 10 statements when studying user opinions of a electronic mail system. The statements were:

1. I find it cumbersome to use the electronic mail system.
2. Learning to operate the electronic mail system is easy for me
3. Interacting with the electronic mail system is often frustrating.
4. I find it easy to get the electronic mail system to do what I want it to do.
5. The electronic mail system is rigid and inflexible to interact with.
6. It is easy for me to remember how to perform tasks using the electronic mail system.
7. Interacting with the electronic mail system requires a lot of my mental effort.
8. My interaction with the electronic mail system is easy for me to understand.
9. I find it takes a lot of effort to become skillful at using electronic mail.
10. Overall, I find the electronic mail system easy to use. [45]

The perceived ease of use was measured according to the answers of the users about how they agreed with the positive and negative statements listed above. Although used for evaluating an electronic mail system, the procedure should be applicable to be used with e.g. lighting control system.

Quesenbery [46] argues that instead of just ease of use, a more valid and comprehensive term is *usability*. More precise definition can then be used to understand user requirements, formulate usability goals and decide on the best techniques for usability evaluations. Definition of usability in ISO 9241 standard is *"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use"* [47].

According to Quesenbery this definition can be expanded, and made more comprehensive, by including five characteristics which must be met for the users of a product:

- Effective
- Efficient
- Engaging
- Error tolerant
- Easy to learn. [46]

These provide a set of characteristics which can be used to organise and analyse information from users. Going beyond the easy of use, these five characteristics help in designing new products or systems as well as in the evaluation part.

Stand-alone systems could also be evaluated with the help of studies such as these, conducting user surveys. Unfortunately, especially the Helvar concepts in focus are just released to the market, so it would have been challenging to find suitable installations outside the premises of Helvar. User satisfaction surveys for actual installations of the three concepts were not in the scope in this thesis, but interviews about the attitude, reception and opinions about stand-alone solutions instead. For the future research, usability user surveys of different stand-alone solutions would be beneficial.

As this thesis focuses on the benefits for different stakeholder groups, besides the end users also the installers, designers and maintenance staff can benefit from the easyness or simplicity of the concept. In the standard ISO 9241 a part of the definition of usability was the extent of efficiency to achieve goals. Efficiency is further defined as *"the resources expended in relation to the accuracy and completeness with which users achieve goals."* [47] This applies to the designing, installing and configuring as well as using phase, the quicker and simpler the processes are, the less resources are needed to get everything complete. While the extent of satisfaction or effectiveness are more closely linked to user feedback, the efficiency evaluation on the other hand can be reasonably done by estimating the required resources.

The three stand-alone concepts are evaluated in the points of view of end users, electrical designers, installers and configuring maintenance staff. To widen the perspective, also a programmable centralised DALI system is included in the evaluation as a non-stand-alone solution. For meaningful comparison, a common evaluation metric must be chosen.

In this context of the thesis, the solutions are chosen to be evaluated by *easyness factor*, which is defined by the resources needed to achieve the desired goal. The less resources required, the higher the easyness factor. Specific goals are e.g. everyday use of the solution for the end user, design of needed cablings and control system schematics for the designer, physical installation of the components needed for the installer and reconfiguring the operation of the solution for the maintenance staff.

The evaluations are approximated to a scale of 1 to 5 with a reference point in the middle. The evaluated easyness factors of Active+ are compared to the reference. That is selected to be on/off switching indoor luminaire in this case, as in the competing product comparison too in chapter 4. Also the centralised DALI lighting control system is included in the evaluation. It should be emphasised that only the easyness is taken into account in these evaluations, not e.g. different features. The results are presented in Table 9.

Table 9 – Evaluated easyness factors of indoor solutions.

	End user	**Electrical designer**	**Installer**	**Configuring maintenance staff**
Task / **Solution**	*Everyday use of the solution*	*Designing the needed cablings and control system schematics*	*Physical installation and initialisation on site*	*Reconfiguring the operation of the solution*
On/off switching indoor luminaires (reference)	**3** Switching the luminaire manually on and off	**3** Designing the placement of the luminaires and switches, also cabling to them	**3** Installing the luminaires, switches and cabling to them	**1** No any convenient way to reconfigure the system besides the cabling changes
Active+	**5** Energy-savings and comfortable operation fully automatic, no user input needed at all	**4** Designing just the placement and mains cables to the luminaires, no need for switches	**4** Installing just the luminaires and mains cables, no need to install switches or control cables, no need for programming	**4** Resetting the luminaire or parameter adjustment with the smartphone application, no training needed
DALI centralised system	**5** Energy-savings and comfortable operation fully automatic with sensors installed	**1** Designing the placement of the control panels, sensors, power supply units and connection interface, as well as DALI cabling between everything in the system	**1** Installing the control panels, sensors, power supply units and connection interface, as well as DALI cabling between all of those, then commissioning and programming everything	**2** Reprogramming the system, DALI training and programming device needed, but no cabling changes

Different easyness factors of Active+ and the other solutions in viewpoints of end users, designers, installers and configuring maintenance staff are illustrated in Figure 40.

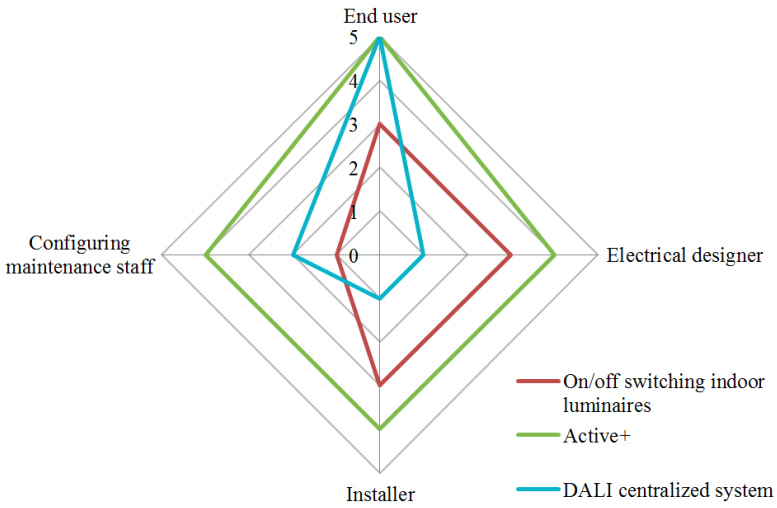

Figure 40 – Evaluated easyness factors of indoor solutions in four stakeholder viewpoints illustrated.

The evaluated easyness factors of nightDim are compared to on/off switching outdoor luminaires, both assumed to be installed with a timer or dusk sensor in the circuitry. As centralised DALI systems are also used in outdoor applications, that is included in the evaluation too. The reference is again the outdoor switching luminaire. Results are presented in Table 10.

Table 10 – Evaluated easyness factors of outdoor solutions.

	End user	**Electrical designer**	**Installer**	**Configuring maintenance staff**
Task / **Solution**	*Everyday use of the solution*	*Designing the needed cablings and control system schematics*	*Physical installation and initialisation on site*	*Reconfiguring the nighttime saving schedule of the solution*
On/off switching outdoor luminaires with timer/sensor (reference)	**5** Normal automated operation of lights going on and off, no user input needed at all	**3** Designing the placement of the luminaires and timer/sensor, also cabling to them	**3** Installing the luminaires, timer/sensor and cabling to them	**3** Configuration by setting the timer to switch the luminaires off during a certain period in the night, compatible timer needed
NightDim with timer/sensor	**5** Energy-savings and comfortable operation also during the night fully automatic, no user input needed at all	**3** Same design effort needed as with switching luminaires also	**3** Same installation effort needed as with switching luminaires also	**4** Remote scene setting with the mains pulses to the driver, no training needed
DALI centralised system	**5** Energy-savings and comfortable operation fully automatic with sensors installed	**1** Designing the placement of the control panels, sensors, power supply units and connection interface, as well as DALI cabling between everything in the system	**1** Installing the control panels, sensors, power supply units and connection interface, as well as DALI cabling between all of those, then commissioning and programming everything	**2** Reprogramming the system, DALI training and programming device needed

Different easyness factors of outdoor solutions are illustrated in Figure 41.

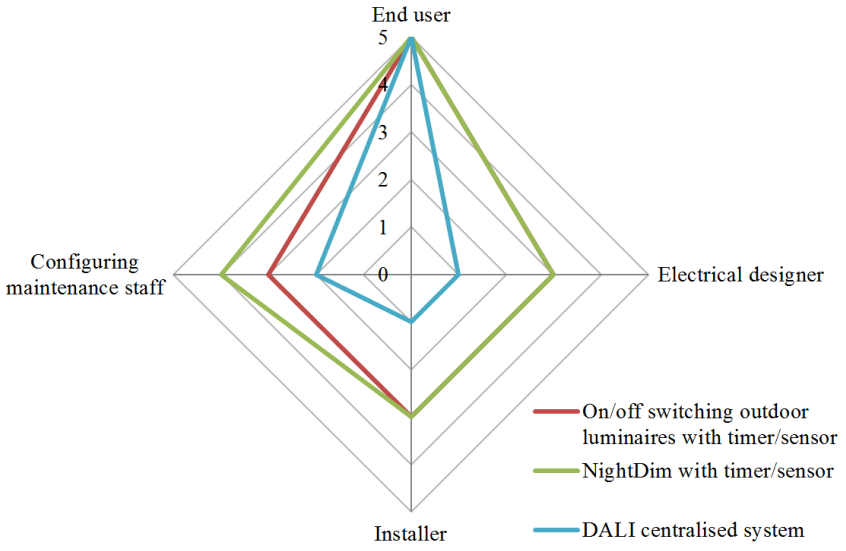

Figure 41 – Evaluated easyness factors of outdoor solutions in four stakeholder viewpoints illustrated.

The evaluated easyness factors of Select the Weather are more difficult to compare, as it is designed to be a human centric lighting concept and not as such directly competing with normal switching luminaires. Basic Select the Weather system without the optional PIR sensor is thus selected to be the reference when comparing to another possible tunable white implementation, centralised DALI system with tunable white luminaires. Results are presented in Table 11.

Table 11 – Evaluated easyness factors of tunable white solutions.

	End user	**Electrical designer**	**Installer**	**Configuring maintenance staff**
Task / **Solution**	*Everyday use of the solution*	*Designing the needed cablings and control system schematics*	*Physical installation and initialisation on site*	*Reconfiguring the operation of the solution*
Select the Weather (reference)	**3** Pushing the buttons on the panel when choosing the desired scene (If PIR connected, then **5**)	**3** Designing the placement of the luminaires and button panels, also mains and DALI cabling	**3** Installing the luminaires, button panels, also mains and DALI cabling	**1** No any convenient way to reconfigure the system besides the cabling changes
DALI centralised system	**5** Energy-savings and comfortable operation fully automatic with sensors installed	**1** Designing the placement of the luminaires, control panels, sensors, power supply units and connection interface, as well as mains and DALI cabling	**1** Installing the luminaires, control panels, sensors, power supply units and connection interface, as well as mains and DALI cabling, then commissioning and programming everything	**2** Reprogramming the system, DALI training and programming device needed, but no cabling changes

Different easyness factors of tunable white solutions are illustrated in Figure 42.

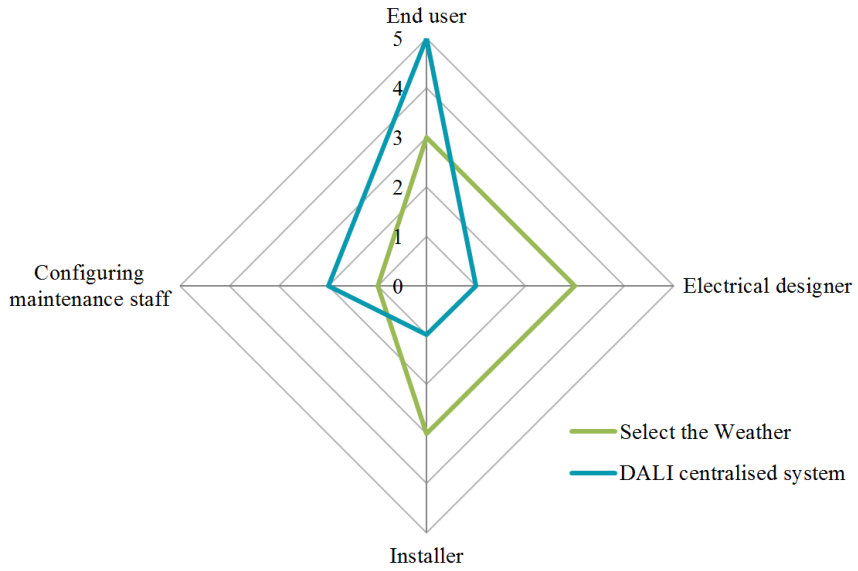

Figure 42 – Evaluated easyness factors of tunable white solutions in four stakeholder viewpoints illustrated.

5.3 Summary and conclusions

In this chapter five cases of original Active concept installations were examined and their energy consumption data analysed. The installation sites were an open-plan office room of Finnish company, a university in Russia, R&D office and type testing laboratory at Helvar premises in Karkkila, Finland and Aalto University offices in Espoo, Finland. Energy savings compared to normal manually switched luminaires were achieved in all of the case examples, ranging from 30% to 55%. Most of the savings were achieved in office environments, while the regular absences in certain parts of the office improve notably the energy saving potential. Also the daylight harvesting in the vicinity of windows contributes to the savings.

The ease of use cannot be measured as accurately however, but various studies have developed definitions and metrics for analysing the ease of use or usability. Evaluating the ease of use with a user survey questions and answers was not in the scope of this thesis, so usability was examined through evaluation of the efficiency, using an easyness factor. That is related to the resources needed to achieve the desired goals. The three stand-alone concepts in the focus in this thesis were evaluated in the viewpoints of end users, electrical designers, installers and maintenance staff.

Active+ performs very well in the evaluation in all viewpoints. It offers efficient functioning without requiring much resources, from the designing phase to the everyday operation.

NightDim is a balanced performer, having much of the same characteristics as a normal on/off switching luminaire, but capable of automated dimming and remote configuring when needed. Scene setting with mains pulses offers nighttime dimming profile adjustments with good easyness factor.

Select the Weather needs the most resources in the designing and installing phase when examining the three stand-alone concepts. This results from the need of DALI cabling and the button panel. The end user operation is not automated by default, but it can be improved by the optional PIR sensor, which increases unfortunately the resources needed for electrical design and installation too. A positive feature that should be noted is that no commissioning or programming is needed at any point.

The centralised DALI lighting control system that was also included in the evaluation requires the most resources from the electrical designer and installer in all cases. DALI system offers better reconfiguration easyness factor than pure switching luminaire or Select the Weather, both of which require physical cabling changes. The best easyness factors for maintenance staff are achieved by Active+ and nightDim. The maintenance of DALI network can of course be simplified by a control panel from which the staff can adjust the system settings, but it needs its own software and graphical, easy to use interface to be implemented and initialised during the installation phase.

Overall, it can be noted that the easyness factor is mostly high for end users in all of these solutions. The major differences are in the resources needed in work tasks of designers, installers and maintenance staff members.

6 Stakeholder interviews

6.1 Interviewed persons

The interviewed persons were chosen to form a group that appropriately represents installers, specifiers and specialists. Specifiers refer here to electrical, lighting and other designers. Interviewed persons are

- Stefan Biström, electrical designer, Granlund
- Ossi Hämäläinen, electrical designer, Sähkösuunnittelu Seppo Räsänen
- Juha Kallas, electrical designer, Yhtyneet Insinöörit
- Mikko Malinen, electrical designer, Sweco building service systems
- Petri Anttila, electrician, Sähkö-Wiik
- Harri Kujamäki, electrician, Aro Systems
- Kimmo Vehkanen, electrician, Sähköasennus Vehkanen
- Pentti Hautala, outdoor lighting specialist, part-time retired (LiCon-AT)
- Antti Tiensuu, outdoor lighting specialist, LiCon-AT
- Marjukka Puolakka, reporter, researcher, Aalto University Lighting Unit
- Jussi Lehtinen, senior planner, the city of Espoo
- Pasi Hyyppä, building service systems specialist, Senate Properties
- Markku Kulomäki, building manager, SKH-Isännöinti
- Antti Kokkonen, energy specialist, SOK
- Heikki Prokkola, office designer, Workspace.

In addition, feedback was gathered also from discussion after a presentation that was made for SOK hotel group members, invited by Jyrki Antinkari, constructor manager of SOK hotels. Interviews were conducted in a non-formal way with sample questions (see Appendix A) and free discussion around them.

To get also international context in the feedback, Helvar contacts from Germany and Switzerland were interviewed too. The interviewed persons answered an email questionnaire (see Appendix B). Interviewed persons are

- Andre Berling, head of the light planning department, Berling Living Lights (Germany)
- Ronny Scherf, product manager of integrated solutions, Honeywell (Germany)
- Henrik Nolte, lighting designer, SSP Schmitz Schiminski Partner (Germany)
- Jörg Hägel, regional sales manager, Glamox Luxo (Germany)

– Gino Gabriele, head of college, Schweizer Licht Gesellschaft (Switzerland).

6.2 Results

The results and the relevant feedback presented here are summarised from the interviews [48-68]. All the views, ideas, opinions and statements gathered here are based on the interviews of the professionals, and not on literature review made for this thesis. The results are divided into four subchapters about Active+, NightDim, Select the Weather and stand-alone solutions in general. Each chapter analyses the main topics e.g. advantages, challenges, suitability etc.

6.2.1 Active+

Active and Active+ raised a lot of interest in general. Most of the questions were about the reliability of the operation and maintenance needs in case of electrical shortages and other unusual situations. The interviewees inquired also about the available luminaires in the market that are designed for or sold with Active+. Some defining questions about the self-learning were asked.

Advantages and benefits

Active+ was received with mainly positive responses. Most thought that the concept and its features were clear, and demand for that functionality was well-founded. Active+ was seen to include practically the functions of a larger and more complex system in a compact, simple and cost-efficient package.

The self-learning was a new concept in lighting control for almost all of the interviewees, and it was considered a great positive asset and innovation. Automated use in general was seen as a good thing, while the behavior of human in control of the system cannot always be predicted or counted on when striving for optimal energy efficiency.

Most considered the greatest benefits of the Active+ the energy saving potential and the easy and inexpensive installation compared to some competing products, especially in retrofit cases with the mains wiring already there. No programming skills or extra cabling is needed when initialising the new lighting system. The possibility to install it just by changing the old luminaire to Active+ luminaire was regarded very convenient.

In the new Active+ version, especially the mobile application was appreciated, as the possibility to change the parameters is regarded essential when the situations, users and environments change. The mobile application was considered as a clever and easy way to adjust the settings. Other benefits that were appreciated were CLO, daylight harvesting and smooth fade times. Also the fact that every luminaire has its own sensor makes the operation efficient with local dimming and sensing.

Many of the designers told that they would recommend gladly Active+ to their customers in case of a suitable project. The reasons mentioned to choose specifically Active+ were e.g. energy savings and ease of use.

Active+ was considered a good way to upgrade an installation, where the customer is already used to a certain simple functionality with e.g. on/off switches or timer.

Challenges and improvement ideas

Many of the interviewees stated that the end users appreciate the possibility to control, switch and dim the luminaires themselves. Different work tasks might call for different light levels. Even if they would not do that, the possibility is often wanted to be there. That is one challenge with the Active+, as there is no easy way to dim the light. A pull switch was widely suggested as an option to Active+ luminaires as there are positive experiences from those in many offices. Mobile application with wireless connection for every end user was also proposed as a convenient way by some people, but not all regarded that as the best way to handle the basic functions.

Many brought up the possibility of the luminaires to be able to communicate with each other. There is already a research project concerning that going on in the company. One idea suggested by many designers was that the luminaires could be linked so that one Active+ luminaire would be the master controlling other non-intelligent luminaires as slaves. This would be enough for many situations with multiple luminaires close to each other decreasing the total costs. Many office rooms have two or three luminaires, and one sensor and intelligence would be sufficient there. One challenge of individual autonomic operation that was brought up is that the lighting could appear disturbingly uneven, if every luminaire adjusts itself regardless of others.

When resetting the luminaire, covering the sensor for one minute is not very convenient for the users, but fortunately the mobile application is there. Many requested that the application should be released also for iOS and Windows Phone. The challenge with the application is that in case of dozens or hundreds of luminaires in need of adjusting, the individual flashing with the phone is really arduous. One option that was proposed was to add a Bluetooth connectivity so that the luminaires could be paired with the mobile phone with Bluetooth. Then it would not be necessary to go so close to the luminaire, and the paired luminaire could broadcast commands to other luminaires.

As the personal adjustment is regarded high these days, and there are lots of offices with changing workstations, one option that was suggested was that the user could set a personal setup from the mobile app to last only for one day, and the default settings would reset for the next working day. One idea was that the user could affect the desired personal light level of the luminaire already during the learning period.

Challenge of Active+ is that after installation, there are no possibilities to upgrade or extend the functionality of the system, as there would be with a DALI system.

In the building managers point of view, a highly-appreciated feature would be a chance

to control the luminaires remotely or receive notifications in case of malfunctions. Maybe challenging to implement in stand-alone solutions though, but this would make the maintenance a lot easier and decrease running costs. A simpler idea that was presented was that the luminaires could include e.g. a small indicator LED that changes its colour and indicates when the luminaire is about to reach the end of its anticipated lifetime. The maintenance staff could then change the luminaires proactively, before they stop their operation and cause irritation among the people in the building.

Marketing

When talking about the marketing, it was recommended that the self-learning and its unique added value should be clearly emphasised, this is something new that also means automatic energy savings. If the customer does not specifically request the product, there must be sound reasons for the extra cost, e.g. ease of use or energy savings. Some of the customers appreciate energy savings also because they boost their "green" brand.

The case examples, study results, measured energy savings and gained benefits are something that interest the customers. The ease of use is usually universally appreciated, so it was mentioned that Active+ could be successful also in consumer market, that should be taken into the consideration. The challenge in marketing is at the moment the need for spreading the knowledge about these solutions to the electrical and lighting designers.

Where is it best suited

Most of the interviewees agreed on that the Active+ solution would suit best a smaller renovation project, where e.g. only lighting is upgraded. This solution offers great functionality with a reasonable investment, and it is regarded as a good solution when there is no need for DALI router system, programmable schedule or scene control for lighting.

For bigger customers and projects Active+ could be too simple, but smaller ones go for affordable solutions and then the extra features are especially appreciated. In case of new buildings and full renovations, control cables and more complex control systems are often installed. Full DALI systems are also more easily upgraded and extended, so bigger customers prefer them. Many new buildings have also lighting integrated into a BMS and thus connected to ventilation and other building services as well.

Many of the interviewees thought that Active+ could work well in office, corridor and storage spaces and even in production facilities. Other places mentioned include the stairwells, coffee lounges, toilets, basements, attics, generally all the places where people sometimes leave the lights on after leaving. Hospitals were also mentioned, with the option to set the lighting to never drop lower than a minimum level for safety reasons.

Private office especially would offer optimal, stable environment for Active+. Changing open-plan office has its own challenges for an Active+ luminaire having already learnt its parameters, but on the other hand the possibility to reset or adjust the operation with mobile application gives a lot of adaptability to new situations. For example serviced offices with changing layouts and walls or partitions could be one environment, where Active+ would do well because of its modifiability. Active+ could also be a suitable choice for a meeting room, if there was a way to control scenes. One idea was to develop some kind of scene control with e.g. mobile application.

Pricing

Many of the people interviewed stated that eventually a lot is depending on the price level of the product. When choosing between solutions, great consideration is given to the initial investment, which should be of course as small as possible. Contradictory there should be as much functionality as possible at the same time though. In renovation projects, the payback time plays a major role. In router systems with a large lighting and control network it was stated to be usually about 12 years, but in smaller projects preferably shorter. Even ten years is hard to sell in indoor lighting projects, five years is quite good already. Payback time of two to three years would be optimum to make the decision for Active+. In general, most of the interviewees working with designing or procuring would have wanted to know what is the price range of complete Active+ luminaires, ready to be installed.

As Active+ luminaire is likely to be more expensive than equivalent normal manually switched luminaire, the price difference has to be reasoned with something, and it is easiest to do with energy savings which can be calculated. Major part of the customers take the life cycle costs into account, but unfortunately some look still only in the initial investment. Also if there are hundreds of luminaires to be installed, the higher price per luminaire caused by sensors and software accumulates notably so smaller renovations are better suited for Active+.

Many DALI and KNX switches and control panels have a high price tag, so it is a benefit that Active+ does not require any additional components. One possible notable benefit results also from the fact that with Active+ there is no actual need for installation of wall switches, which means cost savings in components and labour. Moving the walls afterwards would be easier as well.

Other comments

Ease of use should always be the starting point in design, most interviewees mentioned, regardless of the person using the lighting system, be it an end user or maintenance staff. The user may not be technically skilled, so the luminaire should work in an easy and intuitive way. There has been feedback that even switch & dim system, where the push button has to be kept pressed down for the dimming level to change slowly, is too complicated and customers wanted rotating dimming knob.

Some designers reported that even if there has been complex DALI systems to be able to control the lighting, in open-plan offices those are rarely used, and not always in private offices either.

The end user is concerned about how the lighting and its controlling actually works. And if something does not work as promised, the customers are irritated. The situation is also undesirable, if all the luminaires in the office are operated in a different way.

The PIR sensor sensitivity and the fadetimes are essential, while sometimes there has been negative feedback about the office lighting being suddenly switched off if the workers do not move enough at their workstations. That should not happen with an optimal system.

Normally new luminaires have been procured only when the old ones come to the end of their lifetime, but today they might be changed because of financial reasons and energy-efficiency. The more luminaire manufacturers start selling Active+ equipped luminaires and the more alternatives there are, the better the situation is for electrical designers. The luminaire manufacturers should have clear and accurate product codes and numbers for the luminaires with Active+ so it is easy for the designers to specify the selected luminaires and components. The electrical designers do not want to search for drivers and light sources separately with no guarantee that they will even work together flawlessly.

For the housing cooperatives the initial investment is not always the decisive factor, because the greatest costs come from the maintenance visits when the luminaires stop working. Reliability and long lifetime is essential there. It was said that there would even be demand for a service that ensures the constant and energy-efficient operation of the lighting.

6.2.2 Nightdim

Nightdim gathered lots of comments especially from the outdoor lighting specialists. Couple of interviewees asked if there was a product designed to do the pulsing of the mains to improve the ease of use. Other questions were about the tolerance of power shortages and if it is possible to install this as a retrofit to an old luminaire.

Advantages and benefits

The clearly essential benefit of nightDim according to the people interviewed is the fact that no extra cables or accessories must be installed besides the mains cable. In renovation projects, the costs of digging the ground for new cables are substantial and difficult to justify. The payback time of that kind of installation would be easily over 10 years according to the professionals. With nightDim, all that is needed is the ability to read and follow instructions when configuring the dimming schedule.

Designers said that there is demand for the functionality that dims the outdoor lights down during the nighttime. This concept was regarded as simple, clever and presumably affordable. Greatest benefits were considered to be energy savings, simplicity and reliability. Constant lumen output (CLO) was appreciated as well as the fact that there is no error-prone wireless communication.

The simple installation is a benefit, while there are some experiences of malfunctioning lighting because of a human mistake in the installation, e.g. cables connected to wrong places. A notable advantage is also that the customer can program the scenes itself with no professional help. Good things about nightDim that were mentioned include also the capability to measure the length of the night, long fadetimes in dimming and the idea of controlling the luminaire with mains pulses. Several designers told that they could use nightDim in suitable projects.

Challenges and improvement ideas

Not everyone was satisfied with the pulsing though. Some of the interviewees said that there should be an optional device released that did the pulsing for the user. Better interface for the ease of use could be then e.g. push buttons on the device for different scenes, as people usually prefer a visual interface. Another popular suggestion was that there could be more dimming levels for the dynamic mode, e.g. 75% or 25%. The possibility of a mode switching the lights completely off during the midnight was also proposed. If the customers decided to switch the whole luminaire off themselves in the middle of the night because of energy savings, the clock inside the nightDim would be confused about the length of the night.

Although the more sensors the better is always not the case, some people suggested that an optional PIR sensor could be beneficial, that is often requested in outdoor uses too. The light level could be held relatively low and then raised when the PIR sensor was triggered by occupancy. Occupancy sensing also drives away burglars and uninvited guests. Important thing is also that the luminaire must be vandal resistant.

In case of connected sensors, one idea was to develop self-learning also to nightDim to improve the ease of use. Another suggestion was to integrate real time clock in the nightDim, so that different modes could be programmed for different weekdays. There was some concern among the interviewees because the dimming period does not take the changes in the length of the nighttime throughout the year into account, nor the summer/wintertime. This could be compensated with the help of an e.g. astronomical clock. Some designers said that they prefer drivers with the possibilities to use either DALI, 1-10V or switching control line dimming, giving more versatility for the customer.

Where is it best suited

NightDim would suit best in the environments, where the traffic profile with its peaks and lows is pretty much known, so the dimming scene could be set accordingly. Renovation projects would be suitable for the simplicity of nightDim, in completely new installations it is easier to add the control cables into the infrastructure. In the cities in addition to streets and gardens, shopping malls could be one suitable environment for nightDim.

The large parking halls were also mentioned as they have usually powerful lighting being switched on all the time, consuming a lot of energy. There could be major energy saving potential for nightDim functionality, because outside of the peak hours the light could be effectively dimmed while there are less users in the parking hall.

Marketing

Concerning the marketing material of the concept, it was mentioned that it should be made clear that when controlling many luminaires with nightDim in different groups, every group needs an own switch to do the pulsing. There could be differently grouped luminaires for several streets or parts of the garden, park or backyard.

Other comments

According to the interviewed people, there are suitable opportunities for dimming the lights in the evening in many situations, such as streets, shopping malls and parks, as long as the lights will not be switched off completely.

In the road lighting where the life cycles and payback times are often 20-30 years, there are complex control systems as well as switching relays to dim the road luminaires in use. Making use of the traffic data is getting increasingly more common. So sophisticated systems are already offered in the market, that especially in the road lighting the customers are often ready to invest to get high-grade functionality. Sometimes the installed cables have even the control wire ready there just in case.

The designers said that the outdoor lighting installations in private projects mostly use only on/off switches and timers or light sensors. Most new designs are made with LED luminaires as the first choice for the outdoor lighting. NightDim has thus market potential as the logical next step in efficient outdoor lighting.

6.2.3 Select the Weather

Select the Weather was received with a great interest because of the tunable white technology and the whole human centric lighting ideology behind it. Some questions about the concept were posed and answered, e.g. can the concept be integrated as a part of a more complex DALI installation, can the user set personal scenes and can the buttons be configured to control only specific luminaires in the DALI network.

Advantages and benefits

Many interviewees commented that the automatically changing dynamic weather scene is a fresh and fun idea. Automated use with no need for user input is always a benefit. Appreciation was given for the clear and intuitive userface and buttons on the panel. Several of the interviewed specialists believed that there is potential in the physiological effects of the light on human beings. According to one German interviewee, there has been already positive experiences of tunable white installations in German office buildings.

The functionality is relatively limited with only the four preset scenes and the dimming control, but that was regarded as a good thing. Ease of use benefits from the simplicity, as there is nothing unnecessary, only the most essential functions. One designer would like to see also wall-mounted and spotlight luminaires in Select the Weather family to expand the design possibilities as wide as possible.

It was commented that it seems a good thing that the visual difference of varying colour temperature of the light may not be even recognised, but the physiological effects are still possible. Building owners and employers are of course interested in solutions that improve the efficiency and well-being of the employees working there. Dynamic lighting environment sounded like a positive thing for some of the interviewees, and Select the Weather is a solution they could gladly use in a suitable project. Stand-alone system such as this was seen as especially beneficial because of financial reasons, some builders that do not want a DALI router system could afford to benefit from human centric lighting with a solution like this.

Challenges and improvement ideas

Several of the interviewed people pondered on the question, if there should be a possibility to adjust the colour temperature in a stepless way as the user wishes. This may be an unnecessary function though, as the four preset scenes cover the basic needs. Some exceptions could be e.g. dermatologists and graphic designers though, who would need suitable and highly customisable light for their work environment.

One challenge to consider is also the situation, where in e.g. open-plan office the luminaires would be emitting light of notably different colour temperatures because of different control groups or the dynamic scene being on. This can possibly be distracting for some, or it could easily look like the luminaires were malfunctioning. On the other hand the other challenge in open-plan offices is the fact that different people want different lighting and personal adjustment would be appreciated. Even

though the push-button panel was appreciated, a panel can be a challenging interface especially in the open-plan offices if it is placed too far and out of reach. The user does not want to stand up and go there, and the effect of the adjustment should also be ideally experienced under the actual luminaire in question.

In general people would want more research and case examples to back up the whole human centric lighting concept. The idea was seen as great and promising, but research and studies about the topic would be convincing in the marketing material. Even more important would be real-life case examples to see how the tunable white works and how people have received it. Almost all of the interviewees said that they would like to see a real-life installation or a demo room to see the effect with their own eyes.

Some ideas that came up included the possibility to control this with a mobile application too, with a similarly simple user interface as the button panel and additional settings for the user if needed. There could be also one memory slot and scene for the user to set. One suggestion was to integrate some sensors or functions from Active+ as optional additions to Select the Weather luminaires to achieve major energy savings along with the tunable white. For the use in a dark environment e.g. in the wintertime mornings, it would also be beneficial to build a backlight into the push-button panel.

Marketing

It was agreed on, that the tunable white technology is such a new thing that the customers do not realise to demand it yet. It has to be pushed to the market. One interviewee said that although the possibility to adjust the CCT will supposedly grow more common, it should not be marketed with the claim to increase work efficiency. There are positive results already, but the studies are not indicating absolutely clear evidence yet to back that up. The increase in well-being and work efficiency are however among the best value drivers of Select the Weather.

Where is it best suited

Some of the interviewed people thought that Select the Weather would fit in e.g. meeting rooms, groupwork rooms, restaurants or lounges. Generally speaking places where different moods are wanted and people spend their time only temporarily. These are also spaces that could benefit from one common ambient theme, and not personalised light for everybody as would be best in office use. Some were in the opinion that this could work well also in everyday office work above your desk.

Schools, hospitals and elderly homes were often mentioned as good environments for Select the Weather, as they are places where people spend a lot of time indoors and human centric lighting could revitalise the atmosphere. Although having a lot of potential, challenges lie also in legislation. One professional told that in German schools focus in lighting is heavily in the energy efficiency, not in user comfort and well-being.

As already mentioned, e.g. dermatologists and graphic designers could appreciate the

tunable white light. The industrial shift workers would benefit from the energising effects. This could also fit hotel rooms, if the operator agrees that is suits the brand of the hotel, and Select the Weather could easily be successful in consumer market too. One interesting environment to use the technology in could be fitting rooms, so the shop customers were able to see the clothes in different kinds of light.

Other comments

Interviewed people told that some projects already demand certain colour temperature light in specific needs, but dynamic, changing and tunable white is relatively new thing in the business. Installations with RGB luminaires are sometimes designed for aesthetic purposes, but tunable white has so far been pushed only from the manufacturers side. For electrical designers the most relevant question now is which luminaires are there on the market for Select the Weather solution, and how much do they cost.

One designer supposed that the tunable white luminaires are presumably quite expensive, which might be a challenge for finding buyers. It was mentioned that in e.g. airports and shopping malls there are colour-changing walls and ceilings, so situations to implement also dynamic white exist already.

The interviewees thought that the market potential of Select the Weather is at the moment maybe smaller than e.g. potential of Active+, but the human centric lighting will undoubtedly increase its popularity. Many customers are still conservative, but e.g. the 4000 K colour temperature of neutral white light has become relatively common in new installations and gathered good feedback, so tunable white may well be the next step.

6.2.4 Comments about stand-alone lighting solutions in general

Majority of the interviewed people were in the opinion that stand-alone solutions are really needed and they increase the reliability and the simplicity of lighting control, still offering broad functionality. Some noted that they are being used increasingly in Finland and abroad. Especially useful in renovation projects, stand-alone concepts align themselves as lighting controls that are simple to install and use when the usual option would be just to choose switching luminaires. It was mentioned that it is a great thing to expand the thinking from improving just the luminous efficacy to improving also the functionality. Challenge is that the electrical designers may consider stand-alone solutions as too simple and overlook the easy implementation. There are lots of customers who are not ready for big-scale networked lighting control systems. The important thing would be to spread information about these concepts to the specifiers. Some interviewees stated to usually prefer systems they have already good experiences from, but they are ready to test new systems if the luminaire manufacturers recommend and advertise them.

What is important and what is not

The interviewees were asked to arrange five characteristics of lighting control systems in the order of importance in their point of view: energy efficiency and the costs of use, reliability, ease of use, adaptability and modifiability to different situations, ease and costs of installation. The results were gathered in a chart seen in Figure 43.

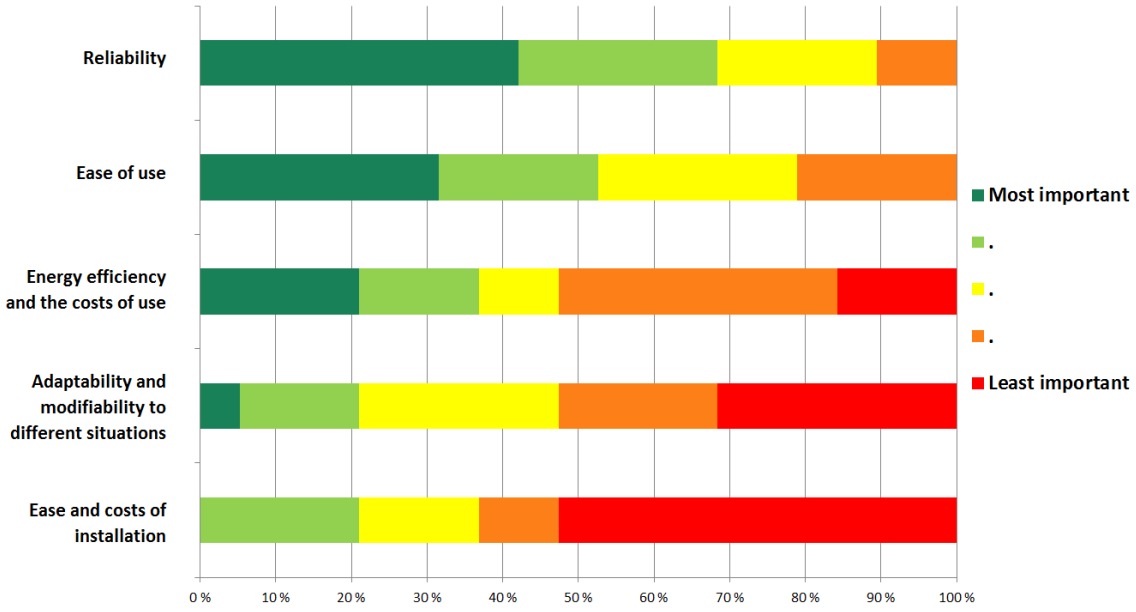

Figure 43 – Opinions of the interviewees on importance of different characteristics of lighting control systems.

The graph shows that reliability is clearly the most important thing, almost half of the interviewees rated that the most important characteristic. Second and third are ease of use and energy efficiency and the costs of use, ease of use rising to the more

important of the two. Adaptability and modifiability to different situations comes fourth, and ease and costs of installation is left as the least important characteristic. Not a single person rated that as the most important, whereas more than half of the interviewees regarded it as least important.

Also upon discussion all of the interviewees agreed that reliability and ease of use are vitally important, those are the features that the customers demand. Both the electronics and the light source should have a decent lifetime and people are ready to pay for reliability if it is taken responsibility for. Long warranty is really appreciated according to the interviewees.

Ease of use is essential, because energy saving features or any other ones are redundant if the user does not know how to operate the luminaire. Too many complicated functions can be a drawback too. Feedback from the ease of use is heard all the time from the end users in installed projects. Common opinion was that most of the end users do not want to spend time or patience to learn how to operate system if it is not intuitive. Product that works reliably and does not need constant adjusting is likely to be successful in the market.

Some end users do not even recognise the importance of reliability and ease of use, as they have been something that has been taken for granted. Only then when something does not work as anticipated, the customers complain. It was stated that the user interface of e.g. mobile application should only include the very basic functions such as on/off and dimming, the advanced options could then be opened and accessed if wanted.

End users have different interests as building owners of course. Some contradictions arise, when e.g. the building owner rents the premises to a company who pays for the electricity. Thus the building owner does not want to invest in energy-efficient products that may cost more, but the owner procures the cheapest possible systems. The leaseholders would want the decrease the electricity bill, but they do not want to invest in infrastructure as they do not own the premises. The goal to save money is common for all parties though.

The interviewed people agreed that stand-alone solutions suit certain situations such as small renovations very well, but not universally everywhere. Some told that the ease of installation and commissioning is really important, as the programming is usually seen as troublesome during the changes in lighting configuration and before the first use. Especially the German professionals emphasised that the best systems are systems which can be programmed by everyone without the help of trained professionals. Some others stated that it is basically only one-time task before use to program and commission the lighting however, and not as problematic as such. It was still mentioned that the stand-alone solutions with no need for extra cabling or programming sound very promising. The customers want cost savings, so that the changes can be reasoned financially. Different functions and modifiability are appreciated as they enable the energy savings. The installation costs add up to overall costs and are thus relevant for everyone. Even if the product would be easy

to use and otherwise great, when too expensive it will not be successful.

Especially the outdoor lighting specialists ranked the energy efficiency high in importance. Electrical designers said that shopping malls and office buildings among others invest notably on energy efficiency. In e.g. airports the investment and installation costs are not the first priority, but aesthetics, functionality and costs of use instead.

In general, some interviewees mentioned that the comfort of the lighting is appreciated and features such as the constant light mode have gathered positive feedback from the end users. Important is also the possibility to adapt, upgrade or extend the system if wanted, which can be a challenge in stand-alone solutions. DALI is seen as an advantage and future-proof standard, whereas 1-10V protocol is outdated. Some interviewees were in the opinion that there should be definitely a possibility to integrate these into a BMS. All in all, as long as the lighting works and there is no need to pay attention to it, it is considered as successful.

Future views

The interviewees had quite clear consensus on the fact that LEDs will dominate the future of the lighting market. Some people predicted that the sales of the lamps and bulbs will decrease, and along the wireless technologies and controllability of the LEDs, controlling the lighting with mobile applications will grow more common.

Besides the mobile control, the individual adjustment of lighting was anticipated to increase its importance and emphasis. In e.g. office environment all the other things are already adjustable: chair, table, computer screen etc. Some people anticipated the situation in the future to be such that once bringing your laptop or smartphone to the work desk the lighting adjusts itself automatically to your memorised individual scene.

Stand-alone solutions were also predicted to become more popular and energy-efficiency will probably be emphasised even more. Some people forecasted that widescale integration of lighting, ventilation and building automation systems will enable the most significant energy savings and increase the comfort in the near future. The tunable white and its benefits are one thing that is also predicted to be one of the focus points in future installations.

The main findings of the stakeholder interviews are summarised and discussed in chapter 7 along with other conclusions. Suggestions for the product development and marketing in the future are also presented.

7 Conclusions: Main findings and future suggestions

The lighting technology market is constantly evolving in the sense of technological development and changing trends in the focus. The modern trends of the lighting industry today include for instance the constantly improving LED technology in the light sources, intelligent and wireless control of luminaires, energy efficiency, well-being of humans and preparation for internet of things era. Stand-alone solutions are reflecting that evolution, while at the same offering value in simple solutions. The simplified changes and future views in the lighting market according to the research made in this thesis are illustrated in Figure 44.

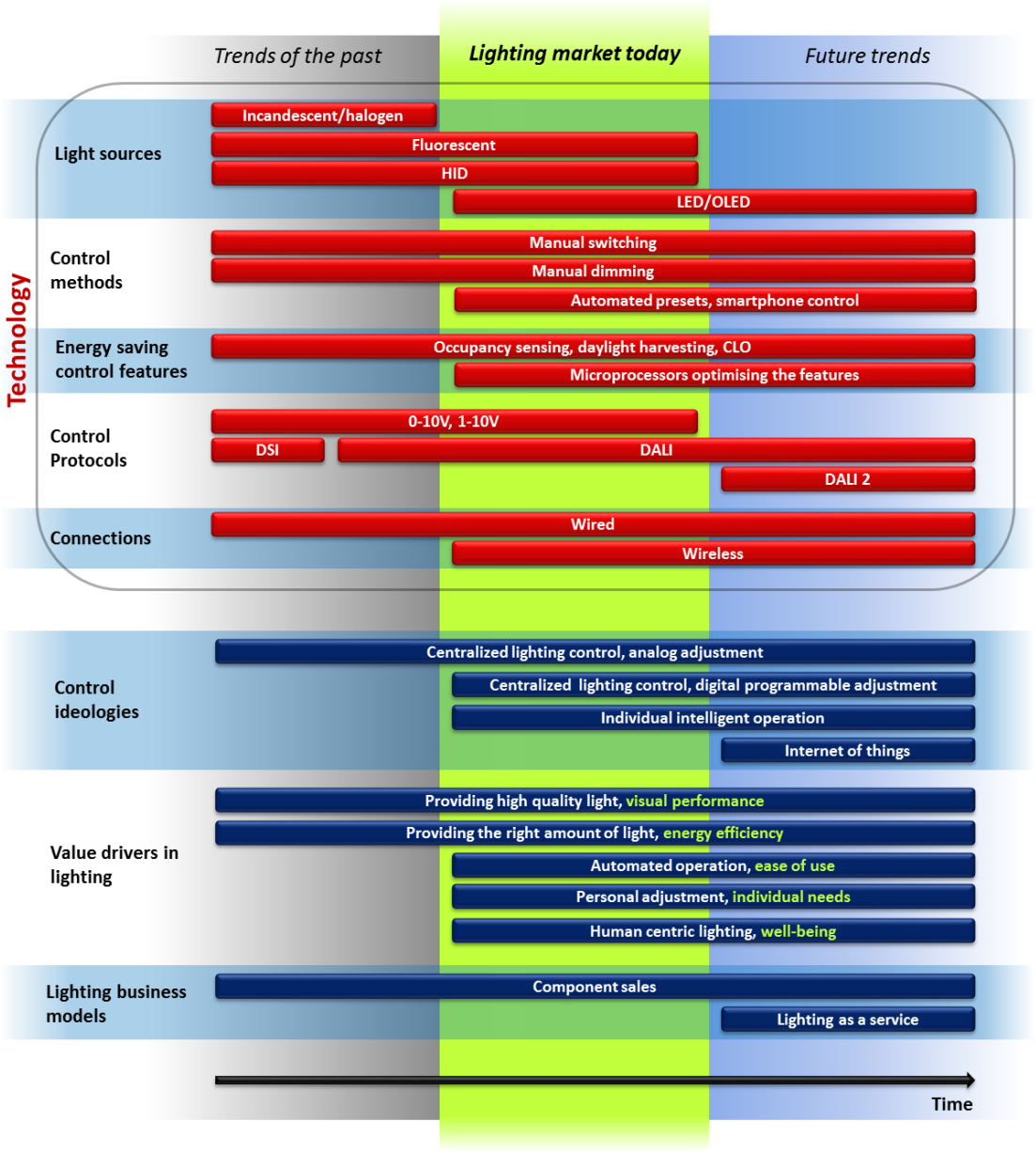

Figure 44 – Conclusive view on the lighting market trends from past to the future.

As many stakeholders involved in new projects are striving for energy savings, the major topic and concern of energy efficiency is mentioned with most of the solutions on the market right now. The original Active has proven to achieve clear energy savings, as examined in chapter 5.1. The data with the first four cases was not measured with calibrated power meters but with drivers though. They still give valid approximations of the energy consumed. The comparison was done to theoretical luminaires, which were assumed to have the same amount of burning hours as the Active luminaire with the most hours. There is always the possibility that the users would choose to keep the luminaires off for long times, but they could be switched on also for the whole day. The case study in Aalto University shows that even when LED luminaires are concerned or when measuring takes place in the winter months with minimum daylight, Active luminaires still operate more efficiently than manually switched ones. It can be estimated that the energy savings with the Active solution are very probable in environments where there is occasional absence or daylight, while still ensuring enough illumination.

As suggested in the interviews in chapter 6, the responsibility for energy efficiency as well as installation, maintenance and operation of lighting in general could be offered as a service. This may well grow popular in the near future, but the pricing of such service could be problematic, being so new business model. Energy consumption data, maintenance needs etc. from different installations would be needed, but they are rarely gathered. A possibility for this in the future could be the wireless networks where the operational data would be sent to cloud service and then gathered in certain way by the company to improve and optimise the services and products.

A major challenge in wireless networks is however the information security, the access to the system and the data must be protected by encryption or other means. As presented in chapter 4, some competing products on the market use wireless communications, whether it means infrared, Bluetooth or ZigBee signals. Most stand-alone systems however are indeed stand-alone in the meaning that they operate in an isolated way, not communicating with each other. The risk of hackers taking control of the units is thus really low if compared to networked system.

When examining more closely the other stand-alone solutions on the market, it can be noted that the self-learning of Active+ is an unique feature, as is also the ability to program nightDim without any equipment besides mains switch. Select the Weather is the single stand-alone solution on the market to offer tunable white without programming. More of the comparison between various solutions is found in chapter 4.

The interviews in chapter 6 give insight on the topic, how do different stakeholders see the stand-alone solutions and their benefits in lighting. The sample of interviewees was intended to be suitable to gather input from as many stakeholders as possible. Interviews were made within the time window and resources of this thesis, and the holiday season during the summer months caused its own challenges in the availability of people. In critical hindsight, some remarks can be made. Although one building manager was interviewed, he was working mostly with residential buildings, so a

facility manager would also have been an interesting addition as the most stand-alone concepts are targeted for public and commercial use. All the electrical designers had experience from lighting, but pure lighting designers would have been also beneficial to be interviewed. Some electrical designers told though, that in their companies the lighting designers rarely plan the control systems of lighting, electrical designers are responsible for that task.

The designers who were interviewed gave their insights about what they have heard from the project customers, and many interviewees were of course also themselves end users of lighting when working daily in their offices. There are still always certain differences between them and the end users with no training or interest in electronics and lighting. If the sole focus was in end users, more surveys and interviews should be made with normal end users in offices, schools, hospitals etc.

With Active+ the interviewed people appreciated the energy saving potential and simplicity the most. There was a lot of discussion about wireless connections and mobile applications, which shows that they are trending now. The designers and specialists thought that there should be a way to control the lighting, but that is difficult to say without interviewing also the normal end users. The designers of course want to choose the products that have the least chance of causing complaints from customers. Controllability lets them to adapt the lighting to their taste, hence the smartphone application, even though intended for the maintenance staff, was a welcome addition. Difficulty of use causes naturally also dissatisfaction, so ease of use was emphasised.

The indicator of the luminaire lifetime left would be very beneficial for building and facility owners and not particularly challenging to implement in technical sense, as the Helvar drivers which have microprocessors inside measure the burning hours in any case. This should be taken into consideration in product development in the future.

Active+ is seen to suit well smaller installations, but for larger installations some people would have needed DALI scalability. There was estimated to be a lot of market potential in the smaller offices. The adjustment possibilities open up new implementation opportunities, e.g. setting the minimum light level to be always on for safety and security reasons in hospital corridors. Communication between luminaires would improve the suitability for bigger buildings, giving the opportunity to relay adjustments to multiple luminaires at once.

NightDim is a concept that has its clear benefits that can be seen in the competitor comparison and interview results. The functionality that is integrated into driver means state-of-the-art simplicity in the structure, and programming the scenes does not require any additional devices or control cables as already mentioned.

While nightDim is striving for easiness, the mains pulsing got some comments about being not so straightforward controlling method as it could. Push-button or similar interface with visual elements could be better, so one possibility for the future would be releasing a device that does the mains pulses for the user. That would improve

the intuitiveness, but on the other hand the strength of nightDim concept is in the fact that no control devices are needed.

A simple and requested improvement for the nightDim would be adding a few more dimming levels, e.g. 25% and 75% to the dynamic dimming scene. One interesting possibility would be to integrate a real-time clock to keep the dimming period synced to the changing seasons especially here in the Nordic countries and removing the need for the external timer, but the challenge is syncing the clock to real time without commissioning or data network. Individually behaving luminaires in outdoor environments can be unfavourable, so the real-time clock might suit better a device installed in cabinet level.

Select the Weather is a solution where the potential value is in the tunable white technology. One challenge lies in the possibility that some designers consider the tunable white only an aesthetic design trick similar to RGB lighting more than a driver for the well-being. Concept itself is considered simple with no major improvement needs. When needing more agile and intelligent control of tunable white, other solutions such as freeDim are available.

The human centric lighting, despite the numerous studies, is not widely implemented and now positive experiences are needed. It must be marketed to customers with the value it can bring, and case installations are required in own premises of companies and customer projects also. In this kind of technology there is always the possibility of actual physical as well as placebo effects, the challenge is that the effects cannot be guaranteed to the customers. They have to experience them themselves.

The major challenge in the viewpoint of specifiers is that there are no deals with luminaire manufacturers yet concerning the three Helvar concepts in the focus of this thesis. The electrical designers interviewed did not want to choose drivers, sensors, light sources and casings separately, but they prefer choosing from the complete luminaire catalogues. Beneficial project would be to set up a web portal to gather cooperating luminaire manufacturers and available Helvar technology equipped luminaires together in an easy to access website. This would improve the information and sales channel to the electrical designers choosing luminaires for varying projects, and efforts should be put also in marketing our products and the web portal.

Case studies of stand-alone installations could be also gathered on the website, as these are new concepts. The interviews indicate that the customers want to see those studies and experiences. Some designers told straight that they prefer to choose something they have experience from.

The idea of stand-alone solutions in lighting was received well among the interviewees, they considered them good solutions for smaller projects in the future. In the survey about the features of lighting control, reliability was seen as the most important factor. This indicates that even though energy efficiency and features are appreciated, they cannot come with the price of reduced reliability. The customers complain if something is not working.

The challenge there is the fact that the reliability was not precisely defined. It could be recognised as e.g. the capability of a system to operate as it is anticipated to operate, the capability of emitting light in the environment or the situation of no components breaking or malfunctioning. In future studies, the clear definition must be taken into account. Other challenge is that every interviewee answered in their own point of view, which differs between the various stakeholders. End user appreciates other things compared to building owner.

Ease of use is appreciated the second most, but the ease of installation the least. This is somewhat contradictory to the interviews about the three concepts, where people complimented the simple installation of the solutions. Energy efficiency is only third, even if it is such an important topic in the current world and among the professionals. The outdoor lighting specialists appreciated it the most, probably because in public sector, which is responsible for a major part of outdoor lighting, different directives, guidelines and recommendations about the energy efficiency build pressure on the decision-makers [69]. At the fourth place was adaptability and modifiability to different situations, which can also be possibly interpreted to concern either the optimisation possibilities to varying environments or then user control possibilities.

The most important characteristics, reliability and ease of use include both subjective and objective factors. As discussed in chapter 5.2, ease of use and intuitiveness can be subjective. However, the needed resources to accomplish tasks in viewpoints of various stakeholders can be evaluated perhaps more objectively and given consideration in product development. Reliability means also the fulfillment of the needs and expectations of the customers, so the marketing should be emphasising the benefits but with certain caution, not promising things are not likely to be achieved. Objective specifications such as quality and thus lifetime of components are the responsibility of the technical side of development. Long enough warranty times are considered really important among the customers, indicating the promise to deliver high-quality products.

As discussed in the end of the chapter 6, smartphone control, domination of LEDs and connectivity of systems are forecasted to increase their importance in the near future. Especially the adoption of new technologies such as tunable white and wireless internet of things networks enables completely new products and business models, which are likely to be emerging in the market sooner or later.

8 Summary

In this master's thesis the foundations, technology and different examples of stand-alone lighting solutions were examined. Stand-alone lighting solutions were defined as luminaire systems that operate without any additional external devices besides possible switches or sensors. The focus was on analysing the possible benefits these solutions can offer to various stakeholders during the life cycle of the solution. The thesis was made for a Finnish company Helvar, which manufactures lighting components and control systems. Three Helvar stand-alone concepts were introduced and their benefits, challenges and improvement possibilities were analysed by interviewing professionals.

In the first part of the thesis the technology, market and some studies of lighting controls were examined. Three of the most common lighting control protocols, analog 0-10V and 1-10V and digital DALI were introduced, as support for them can be widely found in the products on the market today. When discussing stand-alone solutions in lighting, possible advantages were presumed to be simplicity in installation and in use, cost-efficiency in initial costs and energy consumption as well as robustness of systems. Challenges may arise in control of large buildings and future upgradability.

In the third chapter the three Helvar stand-alone concepts were introduced. Active+ is a self-learning luminaire-based system, which measures the environment with a multi-funtional sensor built in the luminaire. It offers guaranteed energy saving features with a simplified installation and automatic optimisation of its operation to the environment, still including the possibility of adjustment by smartphone application. NightDim is an outdoor stand-alone solution, which is capable of being programmed with different nighttime dimming scenes by only switching the mains voltage to the driver on and off. Select the Weather brings the user the chance to benefit from tunable white light, offering four preprogrammed scenes that are designed with human centric lighting in mind.

Competitor comparison introduces a total of 15 other products or product families on the market both in indoor and outdoor applications. Most advertise themselves as stand-alone solutions, but not all of them qualify as such according to the definition in this thesis. Different features, control methods, structures and levels of intelligence are present in the comparison, but the self-learning of Active+, programming method of nightDim and plug&play tunable white functionality of Select the Weather are unique compared to other products discussed in the chapter.

In the next chapter, data of five case installations with original Active luminaires was examined, analysing the energy savings. Ranging from lecture rooms to office and laboratory spaces, energy consumption was lower with Active luminaires compared to manually on/off switching luminaires in all of the cases, achieving savings of 30% - 55%. When comparing the ease of use or easyness in general, the three Helvar concepts enable the completion of many tasks with less resources and effort compared to reference systems of switching luminaires and DALI networked system. Benefits

in easyness were found in the viewpoints of end users, electrical designers, installers and members of configuring maintenance staff.

In chapters six and seven the results of the interviews were presented and analysed. Professionals such as electrical designers, electricians, researchers and various specialists were interviewed for this thesis. The overall response to the Helvar concepts and stand-alone solutions was good, and many people heard about these concepts for the first time. The electrical designers told that they could gladly use stand-alone solutions in smaller projects, as long as the luminaire manufacturers offer these. The professionals appreciated the energy saving potential, simplicity of installation and use as well as human centric lighting potential in the Helvar concepts, with some improvement ideas. When discussing about various characteristics of lighting control systems, reliability, ease of use and energy efficiency were regarded as the most important. Modifiability, adaptability and ease of installation, even if mostly appreciated, were still left to the least important features of these. In the future, personal adjustment of lighting, mobile applications and tunable white were the anticipated trends. In conclusion, stand-alone lighting concepts were seen as competitive solutions on the market, integrating many sophisticated features in simple packages, offering many benefits for different stakeholders from the designers to the end users.

References

[1] *Light's Labour's Lost.* International Energy Agency (IEA) & Organization for Economic Co-operation and Development (OECD), 2006. [Cited 17 Aug 2015]. Available at: http://www.iea.org/publications/freepublications/publication/light2006.pdf.

[2] *The Global LED Lighting Market - Key Trends and Opportunities.* United States: Frost & Sullivan, 2015. [Cited 17 Aug 2015]. Available at: https://tapahtumat.tekes.fi/uploads/26408656/Frost_Tekes_presentation_v2-1096.pdf.

[3] *Solid-state lighting research and development: Multi-year program plan, April 2014 (Updated May 2014).* United States: Department of Energy, 2014. [Cited 27 Aug 2015]. Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2014_web.pdf.

[4] Williams, A. & Atkinson, B. & Garbesi, K. & Rubinstein, F. *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings.* Berkeley, United States: Lawrence Berkeley National Laboratory, 2015. [Cited 17 Aug 2015]. Available at: http://escholarship.org/uc/item/7kc8n19w.

[5] Magno, M. & Polonelli, T. & Beninin, L. & Popovici, E. *A Low Cost, Highly Scalable Wireless Sensor Network Solution to Achieve Smart LED Light Control for Green Buildings.* IEEE Sensors Journal. [Electronic journal]. Vol. 15:5. 2015. P. 2963 -2973. [Cited 27 Aug 2015]. DOI: 10.1109/JSEN.2014.2383996.

[6] *The DALI Guide.* Artistic License Engineering Ltd. [Cited 17 Aug 2015]. Available at: http://www.artisticlicence.com/WebSiteMaster/User%20Guides/the%20dali%20guide.pdf.

[7] DiLouie, C. *Lighting controls handbook.* Lilburn, Georgia, USA: Fairmont Press, 2008. 239 p. ISBN 1-4200-6921-7.

[8] Himanen, M. *Home automation rather for safe or ease living than for control.* In: Seppänen, O. & Säteri, J. Proceedings of Clima 2007 WellBeing Indoors, REHVA World Congress. Helsinki, Finland. 10.-14.6.2007. [Cited 18 Aug 2015]. Available at: http://www.irbnet.de/daten/iconda/CIB7978.pdf.

[9] *Active+ Solution.* Helvar Oy Ab. [Cited 18 Aug 2015]. Available at: http://www.helvar.com/products/ActivePlus.

[10] *NightDim Standalone Solution.* Helvar Oy Ab. [Cited 18 Aug 2015]. Available at: http://www.helvar.com/products/nightDim.

[11] *Select the Weather Standalone Solution.* Helvar Oy Ab. [Cited 18 Aug 2015]. Available at: http://www.helvar.com/products/select-the-weather.

[12] *Lighting the way: Perspectives on the global lighting market, second edition.* McKinsey & Company. [Cited 17 Aug 2015]. Available at: http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/

automotive%20and%20assembly/lighting_the_way_perspectives_on_global_lighting_market_2012.ashx.

[13] *2010 U.S. Lighting Market Characterization, January 2012.* United States: Department of Energy, 2012. [Cited 11 Sep 2015]. Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

[14] *TM-23-11. Lighting control protocols.* New York: Illuminating Engineering Society of North America. 2011. 53 p.

[15] *405 DALI Repeater.* Helvar Oy Ab. [Cited 6 Oct 2015]. Available at: http://www.helvar.com/products/search?st=405%20DALI%20Repeater

[16] Galasiu, A. & Veitch, J. *Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review.* Energy and buildings. [Electronic journal]. Vol. 38. 2006. P. 728-742. [Cited 18 Aug 2015]. DOI: 10.1016/j.enbuild.2006.03.001.

[17] Lucero, A. & Lashina, T. & Terken, J. *Reducing Complexity of Interaction with Advanced Bathroom Lighting at Home (Reduktion der Interaktionskomplexität bei hochentwickelten Badezimmerbeleuchtungssystemen für die Heimanwendung).* I-Com. [Electronic journal]. Vol. 5:1. 2006. P. 34-40. [Cited 18 Aug 2015]. ISSN (printed): 1618-162X. DOI:10.1524/icom.2006.5.1.34.

[18] Shen, E. & Hu, J. & Patel, M. *Energy and visual comfort analysis of lighting and daylight control strategies.* Building and Environment. [Electronic journal]. Vol. 78. 2014. P. 155-170. [Cited 17 Aug 2015]. DOI: 10.1016/j.buildenv.2014.04.028.

[19] *LED lighting control using powerline communication.* EE Times. [Cited 18 Aug 2015]. Available at: http://www.eetimes.com/document.asp?doc_id=1278170.

[20] Boyce, P. *Human Factors in Lighting, Third Edition.* Boca Raton, Florida, USA: CRC Press, 2014. 703 p. ISBN 978-1-4398-7488-2.

[21] Van Bommel, W. *Lighting for work: a review of visual and biological effects.* Lighting Research and Technology. [Electronic journal]. Vol. 36:4. 2004. P. 255-266. [Cited 30 Sep 2015]. DOI: 10.1191/1365782804li122oa.

[22] Juslén, H. *Influence of the colour temperature of the preferred lighting level in an industrial work area devoid of daylight.* Ingineria Iluminatului. Vol. 8:18. 2006. P. 25-36. [Cited 30 Sep 2015]. ISSN: 1454-5837 (paper version), 2068-9853 (online version). Available at: http://lib.tkk.fi/Diss/2007/isbn9789512289622/article5.pdf.

[23] *Quantified benefits of Human Centric Lighting.* LightingEurope, ZVEI, AT Kearney. [Cited 9 Sep 2015]. Available at: http:

//www.lightingeurope.org/uploads/files/Quantified_Benefits_of_Human_Centric_Lighting_April_2015.pdf.

[24] *IDim*. Helvar Oy Ab. [Cited 18 Aug 2015]. Available at: http://www.helvar.com/products/idim.

[25] *Actilume*. Koninklijke Philips N.V. [Cited 18 Aug 2015]. Available at: http://www.lighting.philips.com/main/products/controls/indoor/actilume/.

[26] *Organic Response*. Organic Response. [Cited 1 Sep 2015]. Available at: http://organicresponse.com/.

[27] *E-Sense Tune - lighting becomes personal*. Fagerhult. [Cited 1 Sep 2015]. Available at: http://www.fagerhult.com/Light-control/e-sense/e-Sense-Tune/.

[28] *SMART sensors*. Tridonic. [Cited 28 Sep 2015]. Available at: http://www.tridonic.com/com/en/products/smart-sensors.asp.

[29] *Stand-alone lighting control*. Schneider Electric. [Cited 19 Aug 2015]. Available at: http://www.schneider-electric.co.uk/sites/uk/en/solutions/energy_efficiency/quick-navigation/stand-alone-lighting-control.page.

[30] *Energi TriPak*. Lutron. [Cited 20 Aug 2015]. Available at: http://www.lutron.com/europe/Products/Pages/SingleRoomControls/Energi_TriPak/Overview.aspx.

[31] *Connect radio system*. Schneider Electric. [Cited 20 Aug 2015]. Available at: http://www.schneider-electric.com/en/product-range/2080-connect.

[32] *Exact Movement/presence detectors*. Schneider Electric. [Cited 20 Aug 2015]. Available at: http://www.ops-ecat.schneider-electric.com/ecatalogue/browse.do?cat_id=BU_ISC_60117_L3&conf=basket&el_typ=node&nod_id=0000000035&scp_id=Z000.

[33] *Maestro Occupancy/Vacancy Sensors*. Lutron. [Cited 20 Aug 2015]. Available at: http://www.lutron.com/en-US/Products/Pages/Sensors/Occupancy-Vacancy/MaestroOccVacSensors/overview.aspx.

[34] *Digital Light Agents*. Digital Lumens Inc. [Cited 19 Aug 2015]. Available at: http://digitallumens.com/products/digital-light-agents/.

[35] *Street Light Control by OSRAM - innovative light management system for outdoor areas*. Osram. [Cited 30 Sep 2015]. Available at: http://www.osram.com/osram_com/news-and-knowledge/light-management-systems/product-knowledge/street-light-control/index.jsp.

[36] *Ready2mains*. Tridonic. [Cited 30 Sep 2015]. Available at: http://www.tridonic.com/com/en/products/luxcontrol-ready2mains.asp.

[37] *BEGA Accessories*. BEGA. [Cited 19 Aug 2015]. Available at: http://www.bega.de/en/product/accessories.

[38] *Owlet smart solutions - stand-alone solutions*. Schreder Group GIE. [Cited 18 Aug 2015]. Available at: http://www.schreder.com/be-en/AboutUs/Schreder-owlet-remote-management/Pages/Schreder-Owlet-Stand-alone-solutions.aspx.

[39] *Lighting Controls - Dynadimmer*. Koninklijke Philips N.V. [Cited 19 Aug 2015]. Available at: http://www.lighting.philips.com/main/products/controls/products/dynadimmer/dynadimmer.wpd.

[40] *Xitanium LED Drivers for outdoor applications*. Koninklijke Philips N.V. [Cited 19 Aug 2015]. Available at: http://www.lighting.philips.co.uk/subsites/oem/product_pages/product_portfolio/Xitanium_Outdoor_drivers.wpd.

[41] *Outdoor Lighting Dimming: versatile, energy-efficient and cost-saving solutions*. Osram. [Cited 24 Aug 2015]. Available at: http://www.osram.com/osram_com/news-and-knowledge/light-management-systems/technologies/outdoor-lighting-dimming/index.jsp.

[42] *Tvilight NightSky*. Tvilight. [Cited 6 Sep 2015]. Available at: http://www.tvilight.com/products/nightsky_street_light_control/.

[43] Yan, W. & Hui, S. *An Analysis Into the Dimming Control and Characteristic of Discharge Lamps*. IEEE Transactions on Power Electronics. [Electronic journal]. Vol. 20:6. 2005. P. 1432 - 1440. [Cited 26 Oct 2015]. DOI: 10.1109/TPEL.2005.857507.

[44] Gavioli, M. *Lighting Retrofitting: improving energy efficiency and lighting quality*. Final project. Aalto University, School of Electrical Engineering, Department of Electrical Engineering and Automation, Lighting Unit. Espoo. 2015. 104 p. [Cited 14 Oct 2015] Available at: https://aaltodoc.aalto.fi/bitstream/handle/123456789/16740/final_Gavioli_Marta_2015.pdf?sequence=1.

[45] Davis, F. *Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology*. MIS Quarterly, 1989. Vol. 13:3. P. 319-340. [Cited 22 Aug 2015]. DOI: 10.2307/249008.

[46] Quesenbery, W. *What Does Usability Mean: Looking Beyond 'Ease of Use'*. In: Proceedings of the 48th Annual Conference, Society for Technical Communication. Chicago, United States. 2001. [Cited 22 Aug 2015]. Available at: http://www.wqusability.com/articles/more-than-ease-of-use.html.

[47] Jokela, T. & Iivari, N. & Matero, J. & Karukka, M. *The Standard of User-Centered Design and the Standard Definition of Usability: Analyzing ISO 13407 against ISO 9241-11*. In: Proceedings of the Latin American conference on Human-computer interaction, CLIHC'03 . Rio de Janeirol, Brazil. 2003. [Cited 17 Sep 2015]. Available at: http://www.it.uu.se/edu/course/homepage/acsd/vt11/schema/L2_extra.pdf.

[48] Tiensuu, Antti. Personal interview. 15 Apr 2015.

[49] Biström, Stefan. Personal interview. 16 Apr 2015.

[50] Hyyppä, Pasi. Personal interview. 17 Apr 2015.

[51] Hautala, Pentti. Personal interview. 22 Apr 2015.

[52] Kujamäki, Harri. Personal interview. 23 Apr 2015.

[53] Kokkonen, Antti. Personal interview. 28 Apr 2015.

[54] Puolakka, Marjukka. Personal interview. 4 May 2015.

[55] Hämäläinen, Ossi. Personal interview. 5 May 2015.

[56] Prokkola, Heikki. Personal interview. 6 May 2015.

[57] Kulomäki, Markku. Personal interview. 8 May 2015.

[58] Malinen, Mikko. Personal interview. 18 May 2015.

[59] Anttila, Petri. Personal interview. 20 May 2015.

[60] Antinkari, Jyrki. Personal interview. 27 May 2015.

[61] Lehtinen, Jussi. Personal interview. 28 May 2015.

[62] Kallas, Juha. Personal interview. 5 Jun 2015.

[63] Vehkanen, Kimmo. Personal interview. 24 Jun 2015.

[64] Berling, Andre. Email interview. 22 Jul 2015.

[65] Scherf, Ronny. Email interview. 26 Jul 2015.

[66] Nolte, Henrik. Email interview. 6 Aug 2015.

[67] Hägel, Jörg. Email interview. 13 Aug 2015.

[68] Gabriele, Gino. Email interview. 20 Aug 2015.

[69] *Valaistusta on uusittava! (The lighting has to be renewed!)*. Motiva, STEK. [Cited 6 Oct 2015]. Available at: http://www.motiva.fi/files/2096/Valaistusta_on_uusittava_Tarkeaa_tietoa_kuntien_paattajille.pdf.

A Interview structure model

Stakeholder benefits of intelligent stand-alone lighting solutions

Interview structure model

1 Confidentiality

- Master's thesis, presentation of myself
- Public access to information
- May I record the interview

2 Background

- The interviewee's background and the position

3 Active+

- If familiar, what were your thoughts of the concept, when you first heard about it?

- Presentation of the concept now -

- Did your opinion change after the presentation?
- Is the concept clear to you?
- Have you used / seen other similar products?
- What is especially good in the concept?
- What did you not like or what should be improved?
- What kind of price you would be willing to pay for this?
- Why would you choose precisely this concept, or why not?
- How interested would you be in buying / using the Active+ solution?
- What kind of situation or use would see the product to be best suited for?

4 nightDim

- If familiar, what were your thoughts of the concept, when you first heard about it?

- Presentation of the concept now -

- Did your opinion change after the presentation?
- Is the concept clear to you?
- Have you used / seen other similar products?
- What is especially good in the concept?
- What did you not like or what should be improved?
- What kind of price you would be willing to pay for this?
- Why would you choose precisely this concept, or why not?
- How interested would you be in buying / using the Active+ solution?
- What kind of situation or use would see the product to be best suited for?

Figure A1 – Page 1 of the interview structure model.

5 Select the weather

- If familiar, what were your thoughts of the concept, when you first heard about it?

- Presentation of the concept now -

- Did your opinion change after the presentation?
- Is the concept clear to you?
- Have you used / seen other similar products?
- What is especially good in the concept?
- What did you not like or what should be improved?
- What kind of price you would be willing to pay for this?
- What do you think about the opportunities of tunable white technology?
- Why would you choose precisely this concept, or why not?
- How interested would you be in buying / using the Active+ solution?
- What kind of situation or use would see the product to be best suited for?

6 Stand-alone lighting concepts in general

Could you put the five lighting control characteristics in order of importance in your point of view:

Reliability
Ease of use
Energy efficiency and the costs of use
Adaptability and the modifiability to different situations
Ease and costs of installation

- How would you see the market and the technology develop in the near future?
- What do your customers hope and expect from the control solutions?
- Do you have activities abroad, have you noticed any differences between them and domestic customers?
- What do you think in general about the idea of controlling lighting as a stand-alone solution?
- What are the advantages or challenges you would see in this?

7 Finally

- Any more questions or comments?
- Do you have any people in mind, who you would recommend me to interview?

Figure A2 – Page 2 of the interview structure model.

B Email questionnaire

Master's Thesis about stakeholder benefits of intelligent stand-alone lighting solutions

E-mail questionnaire, the answers will only be used anonymously in the Thesis and possibly in Helvar internal purposes.

1 About you

Could you tell briefly what is your position in the company and what do you do

2 General

How familiar are you with the term *"stand-alone solutions"*?

Not at all familiar Slightly familiar Moderately familiar Very familiar

Other comments

Which concepts of ours have you heard of before?

- Active+
- nightDim
- Select the Weather

Through which channel do you normally hear about these?

STAND-ALONE CONCEPTS

Next three parts are about the new Helvar stand-alone lighting concepts on the market. Please answer and share your views on at least one of those. Preferably choose the one that seems like the most interesting to you and your business, and/or the one you are familiar with. You can find more detailed information from the weblinks after the descriptions. You are free to ask questions in the end of the parts, I will get back to you and do my best to answer those!

3 Active+

Active+ is a stand-alone lighting solution for e.g. office, classroom and corridor spaces. It features self-learning algorithms with PIR and light sensors to be able to adjust the operation automatically to offer as high quality and energy efficient lighting as possible with no programming or commissioning. Newest version, Active+, was released in the beginning of September, with small multisensor to be attached straight to the driver with no need for separate power supply. In addition there is a mobile application developed for the solution, enabling the user to adjust the parameters of Active+ luminaire with smartphone if wanted.

1

Figure B1 – Page 1 of the email questionnaire.

More information http://www.helvar.com/products/ActivePlus

Application note:
http://www.helvar.com/sites/default/files/product_datasheets/Active%2B%20application%20note_24082015_0.pdf

How interesting is Active+ to your business?

What are the greatest benefits of Active+?

Is there something to be improved in the concept?

Where would you see that Active+ is best suited?

Other comments or questions

4 NightDim

NightDim controllable LED-drivers are designed for outdoor use with the ease of installment and adjustability in mind. No extra devices or cables are needed, nightDim drivers can be controlled and set to different lighting scenes with only pulses from the main switch.

More information http://www.helvar.com/products/nightDim

Brochure:
http://www.helvar.com/sites/default/files/nightDim_17032015.pdf

How interesting is nightDim to your business?

What are the greatest benefits of nightDim?

Is there something to be improved in the concept?

Where would you see that nightDim is best suited?

Figure B2 – Page 2 of the email questionnaire.

Other comments or questions

5 Select the Weather

Select the weather is a human centric lighting concept with benefits in physiological effects of light. The adjustable colour temperature can affect the well-being and alertness of users. The concept has four factory pre-programmed scenes with three static modes and the fourth dynamic weather scene with automatically changing colour temperature to create a subtle, dynamic light environment. Everything works out-of-the-box with no commissioning.

More information http://www.helvar.com/products/select-the-weather

Product Bulletin:
http://www.helvar.com/sites/default/files/product_datasheets/Product%20Bulletin_Select_the_Weather%20FINAL_2.pdf

How interesting is StW to your business?

What are the greatest benefits of StW?

Is there something to be improved in the concept?

Where would you see that StW is best suited?

What do you think about the future views of tunable white technology?

Other comments or questions

Figure B3 – Page 3 of the email questionnaire.

6 Stand-alone concepts in general

Arrange the next characteristics of lighting control system in the order of importance in your point of view, elaborate if needed

- Energy efficiency and the costs of use
- Reliability
- Ease of use
- Adaptability or modifiability to different situations
- Ease and costs of installment

Most important				Least important

Stand-alone concepts mean solutions that have value-adding features, but are intended to work independently by plug&play principle, no programming or complex installation required and as easy to use as possible.

What do you think about the idea of stand-alone solutions in lighting?

What kind of benefits or challenges do you see in these?

Other comments or questions

Thank you for answering the questionnaire!

I will send the Master's Thesis to you once completed, thank you for contributing! Please indicate if you don't want your name in the list of interviewed people in the Thesis.

Best regards,

Toni Malinen

Helvar freedom in lighting

4

Figure B4 – Page 4 of the email questionnaire.